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PB-254 570

PROCEEDINGS OF CONFERENCE ON ENVIRONMENTAL QUALITY SENSORS (SECOND) HELD AT NATIONAL ENVIRONMENTAL RESEARCH CENTER, LAS VEGAS, NEVADA ON OCTOBER 10-11, 1973

ENVIRONMENTAL PROTECTION AGENCY

10 DECEMBER 1973

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PB 254 570

PROCEEDINGS
SECOND CONFERENCE ON ENVIRONMENTAL QUALITY SENSORS

National Environmental Research Center
Las Vegas, Nevada
October 10-11, 1973

Environmental Protection Agency
Office of Research and Development
Office of Monitoring Systems
Washington, D.C. 20460

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780

DECEMBER 10, 1973

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FOREWORD

The Second Conference on Environmental Quality Sensors provided an interchange of information between the Environmental Protection Agency's (EPA) research scientists who are developing and testing improved ways of monitoring the quality of the environment and the Agency's ten Regional Offices. In order to achieve the desired communications and response from the participants, the attendance was limited to those in EPA who are utilizing, or are planning to employ remote sensing technology in their planning and regulatory function. Participating with EPA in the conference were other Federal and State agencies, universities and several industrial research organizations. Complete texts of the technical papers are included and constitute the major portion of this document. Presentations by regional and program offices focused on how remote sensing could be effectively utilized in their respective geographical areas. Numerous applications and program requirements were presented and are being reviewed with the Regions.

The program and agenda were prepared by the Steering Committee consisting of sensor experts within the agency. They are as follows:

Murray Felsher - Office of Enforcement and General Counsel
Robert F. Holmes - Office of Monitoring Systems
Donald R. Jones - Office of Hazardous Materials
Office of Air and Water Programs
John D. Koutsandreas - Office of Monitoring Systems
Anthony F. Mentink - NERC, Cincinnati
John W. Scotton - Office of Monitoring Systems
Donald T. Wruble - NERC, Las Vegas

The technical presentations are arranged in the order that they appear in the Conference Program Agenda.

John D. Koutsandreas
Conference Chairman

December 10, 1973

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

NOV 28 1973

OFFICE OF
RESEARCH AND DEVELOPMENT

SUBJECT: Preliminary Report of the Second Environmental Quality Sensor Conference

FROM: Chairman, Second Environmental Quality Sensor Conference

TO: Assistant Administrator for Research and Development

THRU: Acting Director
Equipment and Techniques Division

Deputy Assistant Administrator for Monitoring Systems

The Second Environmental Quality Sensor Conference was convened in Las Vegas on October 10-11, 1973. The purpose of the conference, as stated by Mr. Willis B. Foster, was to provide a forum for discussing the role of remote sensing in the Agency's program to those who have a responsibility for monitoring. He invited all of those present to work cooperatively towards applying those methods and techniques which could be effectively utilized by the Environmental Protection Agency (EPA), and hold the potential of becoming standard methods in monitoring the environment. Participation of approximately 130 individuals included representatives from each EPA Region, National Environmental Research Center (NERC), and from several program offices. Key representatives from other Federal agencies, universities and industry were also present.

The conference was organized into ten sessions which included 25 papers. A summary of the technical sessions is included in the attached. The conference proceedings are to be published and disseminated to all participants. Copies of the proceedings will be available to the general public through the Government Printing Office about January 1974.

Prior to the conclusion of the two day conference, regional and program office presentations focused on how remote sensing could be effectively utilized in their respective geographical areas. Numerous applications and program requirements were suggested by the speakers, some of which are currently underway and being coordinated by the Office of Monitoring Systems and NERC-Las Vegas. A few of the more urgent regional applications for monitoring by remote sensors are listed:

1. Salinity control in agriculture
2. Water reuse in the West
3. Brown cloud over Denver
4. Agricultural runoff
5. Eutrophication
6. Strip mining
7. Pest infestation
8. Industrial outfalls
9. Everglades protection
10. Power plant thermal plumes
11. Oil spills
12. Acid mine drainage
13. Ocean dumping
14. Solid waste management
15. SO_2 from copper smelters
16. Sedimentation and algae productivity

From the above, it appears that the Regions and the program offices are prepared to utilize remote and automated in-situ technology in numerous applications.

In response to the Conference Committee invitation, Dr. Virginia Lee Prentice, National Academy of Sciences (NAS), Committee on Remote Sensing Programs for Earth Resource Surveys (CORSPERS) stated that the NAS-CORSPERS Environmental Measurements Panel would prepare a formal response to EPA on the Academy's recommendations for future research and development for environmental quality sensors. Dr. Prentice suggested increased use of data from the National Aeronautics and Space Administration's Earth Resources Survey Program. She specifically encouraged the utilization of high resolution absorption spectroscopy for measuring atmospheric constituents to a few parts per billion and the use of the micrometer band for water temperature measurements.

It is felt that the conference achieved the objective in communicating new monitoring technology to the Regions, NERC's and program offices. Through the participation of the other Federal agencies we have stimulated some technology exchange which can be applied directly to EPA monitoring problems. Some large gaps existing between present technology capabilities and needs of the Agency are being identified.

During the conference the submission of the Environmental Research Need statements pertaining to remote and automated in-situ requirements was emphasized. A more personal relationship was encouraged in the preparation of the statements to assure that the resultant plans are responsive to the program requirements.

Because of the EPA involvement with other Federal agencies, more formal recognition of interagency activities and communications relevant to remote sensing should be established. It is recognized that there are many informal contacts and exchanges between EPA NERC's and Regions that are not recognized at EPA Headquarters. This could lead to uncoordinated activities which are inconsistent with strategies designed to meet the requirements of program offices. Formal recognition and guidance by the appropriate organizations within the Office of Research and Development will lead to a more useful sensor and/or data product and the timely exchange of research data as required by the Agency.

The lack of interdisciplinary coordination among remote sensor specialists in the Agency prompts the need for an intra-agency remote sensing coordinating and advisory committee in order to more fully utilize remote sensor technology. Such a committee was suggested by many of the Agency participants. The committee should consist of members from all Regions, NERC's and program offices working with remote sensors, to form a working advisory group within EPA. Some of the functions suggested for the committee are listed.

1. Intra-agency coordination of remote sensing efforts and liaison responsibilities within EPA and at interagency levels.

2. Identification, development and prioritization of both short-term and long-term support requirements/ objectives which are amendable to a remote sensing approach.

3. Definition, planning and recommendation of a realistic environmental remote sensing program to meet program office requirements.

4. Review of existing and planned EPA remote sensing programs assessing their adequacy toward meeting program office requirements and objectives.

Additional functions and scope of this committee will be formulated and forwarded to the appropriate offices for review, comment and approval.

In closing, it is felt that notable advances were made at this conference in implementing the remote and automated sensor technology toward the Agency's monitoring requirements. It was the general concensus that remote sensing will not replace many present methods of manual sampling but will be used to point out specific locations where environmental problems exist, so that in-situ methods may be more effectively and efficiently employed. In this regard, I believe the conference was a success and more than paid for the time, effort and funds involved.

John D Koutsandreas

John D. Koutsandreas

Attachment

SUMMARY OF TECHNICAL SESSIONS
SECOND ENVIRONMENTAL QUALITY SENSOR CONFERENCE

I. National Environmental Research Center-Las Vegas Programs

The aerial remote sensing system being developed was described, including aircraft imagery and data acquisition systems, as well as ground data processing systems. A LIDAR sensor being developed for aerial monitoring of aerosol characteristics and mixing layer measurements was demonstrated. The Zeeman effect atomic absorption spectrometer is being evaluated for direct analysis for mercury in the parts-per-billion range. This instrument was designed and built for the National Science Foundation and the Atomic Energy Commission by the Lawrence Berkeley Laboratory. The application of helicopter-borne instrumentation for data gathering in the Los Angeles Reactive Pollutant Program, is providing valuable information.

II. National Aeronautics and Space Administration-Langley Research Center Sensor Programs

Work performed under the Environmental Protection Agency (EPA)/National Aeronautics and Space Administration interagency agreements for the evaluation of remote sensors for water pollution detection and monitoring was presented. The results of laboratory tests, fixed height platform field tests, and helicopter flight tests of a four frequency laser system induces fluorescence in algae for remote monitoring. Measurement results are repeatable and comparison with "ground truth" data raise questions about which is a more accurate measure of algae quantity. An imaging multispectral scanner was flight tested and the data analyzed for the identification of various pollutants. A technique based on film and filters for quantitatively measuring the amount of chlorophyll in a water body was discussed. Understanding what physical processes are involved in sensing a pollutant, both from the sensor and pollutant viewpoint, are paramount in this research. The status of work underway on investigations dealing with passive microwave radiometers, multispectral scanners and sewage outfall detection was presented.

III. Air Quality Sensor Developments

The siting of sensor installations responsive to programmatic needs was discussed for the St. Louis Regional Air Pollution Study. Utilization of the latest accepted air monitoring equipment was discussed. The use of laser technology for long path measurement of atmospheric pollutants is considered a promising candidate for monitoring carbon monoxide and ethylene. Optical techniques are being effectively utilized for monitoring stationary sources. Instrument research specifications for air emission controls were presented.

IV. Water Quality Sensor Development

The basic theory and applications of recent water quality contact sensors were presented. The measurement of total cyanides by selective ion electrodes appears practical with some pretreatment. Automated in-situ sensors are being utilized over 200 river miles by the Minneapolis-St. Paul Metropolitan Sewer Board. Extended measurements (beyond the basic property parameters) are unique, requiring selectivity in sample preparation to optimize sensor performance. The phase-out of systems designed for continuous monitoring was due to improper maintenance, poor selection of sensors, or unavailability of preferred sensors.

V. Environmental Thematic Mapping

Land use is a key factor in determining environmental quality in most parts of the Nation. Regular monitoring of change in quality and use of land and water resources is required. Thermal mapping data can provide information on the location of sources of potential pollution from landfills, from chemical and petroleum storage facilities, and from sewage lagoons and feedlot operations. Techniques of acquiring remote quantitative measurements of surface water temperature with an infrared scanner in an aircraft are proven. Computer produced images having gray levels corresponding to absolute temperature (within $1/2^{\circ}$) and numerical grids giving absolute temperatures at uniform levels are shown. Remote sensor imaging can assist in the location and characterization of pollution sources, assessment of impact, projection of trends, location of potential problem areas, and the assessment of preventive measures. Recommendations were presented for an operational system which provides data during suboptimum aerial photographic conditions.

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VI. Oil and Hazardous Materials Sensors

A detection and identification of specific petroleum products on water surfaces and volumetric determination of oil spills through remote sensing were shown to be not only practical but also adaptable operationally for surveillance, oil spill cleanup support, and enforcement purposes. The use of environmental photo interpretation keys for identification and evaluation of oil and hazardous materials production, storage, and processing facilities has significant potential as a spill prevention surveillance function.

VII. Satellite Environmental Monitoring Applications

A methodical approach, using aircraft and satellite data, was presented for locating and monitoring polluted mine drainage. Such factors as texture, shape, and spectral response are analyzed and compared to previously obtained data. Computer processing techniques have been developed for identifying low, medium, and highly reflective types of water which are associated with various concentrations of suspended matter. Turbidity patterns, acid disposal plumes and convergent water boundaries along with high concentrations of pollutants have been detected from satellite imagery. Space data relay systems provide for automatic collection of data from in-situ environmental sensors. These networks are supplying data to regulatory agencies on a daily basis.

VIII. Environmental Monitoring Applications

Through careful preflight planning, in-depth analysis and coordination with limited ground truth parties it is possible to utilize aerial photography, both vertical and oblique to monitor water quality and prepare evidence for court trials. Quantitative data on water quality can be obtained from remote sensor data. Some ground truth data are preferred in order to quantify the density levels of the imagery. From this point it is a simple matter to establish correlation between gray-level and selected water quality parameters. The present state-of-the-art in remote sensing can produce useful data for monitoring and enforcement actions for EPA. The use of the data in operational programs can also bring about advancement of the state-of-the-art by recognizing gaps in current procedures.

ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH & DEVELOPMENT
OFFICE OF MONITORING SYSTEMS
SECOND CONFERENCE ON ENVIRONMENTAL QUALITY SENSORS
NATIONAL ENVIRONMENTAL RESEARCH CENTER
LAS VEGAS
OCTOBER 10 AND 11, 1973

-- CONFERENCE AGENDA --

Tuesday - October 9

4:00 p.m. - 8:30 p.m. - Registration: Royal Las Vegas Hotel Lobby

Wednesday - October 10

8:00 a.m. - 8:30 a.m. - Late Registration - NERC-Las Vegas Administration Building

8:30 a.m. - 9:00 a.m. - Conference Convenes
Mr. John D. Koutsandreas - Chairman

Dr. Delbert S. Barth - Welcome

Mr. Willis B. Foster - Keynote Address

Mr. John D. Koutsandreas - Conference Program Overview

I. 9:00 a.m. - 10:10 a.m. - NERC-Las Vegas Programs

Mr. Donald T. Wruble, NERC-Las Vegas

- Imagery Acquisition System - Messrs. Leslie M. Dunn and Albert E. Pressman, NERC-Las Vegas
- Aerial Air Pollution Sensing Techniques - Mr. Roy B. Evans, NERC-Las Vegas
- LIDAR for Remote Monitoring - Dr. S. Harvey Melfi, NERC-Las Vegas
- Evaluation of the Zeeman Atomic Absorption Spectrometer - Mr. Erich Bretthauer, NERC-Las Vegas

10:10 a.m. - 10:30 a.m. - Coffee Break

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II. 10:30 a.m. - 11:40 a.m. - NASA-Langley Sensor Programs

Mr. James L. Raper, NASA-Langley

- Multi-Wavelength Laser Induced Fluorescence of Algae In Vivo: - A New Remote Sensing Technique - Mr. P. B. Mumola, Mr. Olin Jarrett, Jr. and Mr. C. A. Brown, Jr.
- Remote Detection of Water Pollution With Multichannel Ocean Color Scanner: - An Imaging Multispectral Scanner - Mr. Gary W. Grew
- Summary of NASA-Langley Remote Sensing Activities Under The EPA Interagency Agreements: - Potential For Regional Applications - Mr. James L. Raper, NASA-Langley
- The Use Of Near-Infrared Photography For Biodegradable Pollution Monitoring Of Tidal Rivers - Mr. Walter E. Bressett, NASA-Langley and Dr. Donald E. Lear, Jr., EPA Annapolis Field Office

11:40 a.m. - 1:15 p.m. - Lunch

III. 1:15 p.m. - 2:10 p.m. - Air Quality Sensor Developments

Mr. Charles E. Brunot, Office of Monitoring Systems, OR&D

- The St. Louis Regional Air Pollution Monitoring System - Mr. James Reagan, NERC-RTP
- Long Path Optical Measurement of Atmospheric Pollutants - Mr. A. E. O'Keeffe, NERC-RTP
- Performance Specifications for Stack Monitoring Systems - Mr. James B. Homolya, NERC-RTP

IV. 2:10 p.m. - 3:20 p.m. - Water Quality Sensor Development

Mr. A. F. Mentink, NERC-Cincinnati

- In-Situ Sensor Systems for Water Quality Measurement - Dr. K. H. Mancy, University of Michigan
- Description of Selected Available Sensors - Dr. Julian Andelman, University of Pittsburgh
- Metropolitan Sewer Board Water Quality Monitoring Program for the Minneapolis-St. Paul Metropolitan Area - Dr. Russell Susag, St. Paul Metropolitan Sewer Board
- Water Quality Sensing in Some Eastern European Countries - Dr. Peter Krenkel, Vanderbilt University and Dr. Vladimir Novotny, Marquette University
- An Airborne Laser Fluorosensor for the Detection of Oil on Water - Dr. H. H. Kim, NASA-Wallops Station

3:20 p.m. - 3:40 p.m. - Coffee Break

V. 3:40 p.m. - 5:05 p.m. - Environmental Thematic Mapping

Mr. John D. Koutsandreas, Office of Monitoring Systems, OR&D

- Remote Sensing and Identification of Critical Area of Environmental Concern - Dr. James R. Anderson, USGS
- Remote Sensing Data, A Basis for Monitoring System Design - Mr. James U. Taranik, Iowa Geological Survey
- Recent Development in Remote Thermal Mapping of Water Surfaces - Mr. E. L. Tilton III, Mississippi Test Facility
- Remote Sensor Imagery Analysis For Environmental Impact Assessment - Messrs. C. P. Weatherspoon, J. N. Rinker, R. E. Frost and T. E. Eastler, U.S. Army Engineers, Topographic Laboratories
- Aerial Spill Prevention Surveillance During Sub-Optimum Weather - Messrs. Robin I. Welch, Allan D. Marmelstein and Paul M. Maughan, ERTSAT

5:05 p.m. - 5:35 p.m. - NERC Las Vegas Tours

Laser Demonstration - Dr. S. Harvey Melfi

Imagery Processing and Interpretation Lab Tour - Mr. Albert E. Pressman and Mr. Leslie M. Dunn

Thursday - October 11

VI. 8:30 a.m. - 9:55 a.m. - Oil and Hazardous Materials Sensors

Mr. Donald R. Jones, Division of Oil & Hazardous Materials, OAWP

- Single Wave Length Fluorescence Excitation for On-Site Oil Spill Detection - Mr. J. Jadamec, U.S. Coast Guard
- The Remote Detection and Identification of Surface Oil Spills - Mr. Herbert R. Gram, Spectrogram Corporation
- Environmental Keys for Oil and Hazardous Materials Detection - Messrs. Charles L. Rudder and Charles J. Reinheimer, McDonnell Aircraft Company
- Video Detection of Oil Spills - Mr. John P. Millard, NASA-Ames and Lieutenant Commander Gerald F. Woolever, U.S. Coast Guard
- Measurements of the Distribution and Volume of Sea-Surface Oil Spills Using Multifrequency Microwave Radiometry - Dr. James P. Hollinger and Mr. R. A. Mennella, Naval Research Laboratory
- The National Environmental Monitoring System - Mr. Theodore Major, The Magnavox Company

9:55 a.m. - 10:15 a.m. - Coffee Break

VII. 10:15 a.m. - 12:00 Noon - Satellite Environmental Monitoring Applications

Mr. John D. Koutsandreas, Office of Monitoring Systems, OR&D

- Skylab Application to Environmental Monitoring - Dr. Victor S. Whitehead, NASA Johnson Space Center
- Environmental Applications of the Earth Resources Technology Satellite, D. T. Schultz, General Electric Co., Space Division, Charles C. Schnetzler, Goddard Space Flight Center
- ERTS-1 Detection of Acid Mine Drainage Sources - Messrs. Elliott D. DeGraff and Edward Berard, Ambionics, Inc.
- Water Quality Analysis Using ERTS-A Data - Dr. Harry Kritikos, University of Pennsylvania and Mr. Hubert Smith, EPA, Region III
- Application of ERTS-1 to Coastal Environmental Problems - Dr. V. Klemas, University of Delaware
- Data Collection Platforms for Environmental Monitoring - Mr. J. Earle Painter, NASA-Goddard

12:00 Noon - 1:30 p.m. Lunch

VIII. 1:30 p.m. - 2:40 p.m. - Environmental Monitoring Applications

Mr. Robert F. Holmes, Office of Monitoring Systems, OR&D

- Aircraft Monitoring of Lake Superior Pollution Sources - Dr. J. P. Sherz and Mr. J. F. Van Domelen, University of Wisconsin
- LIDAR Polarimeter Measurements of Water Pollution - Dr. J. W. Rouse, Jr., Texas A&M University
- Detection of Dissolved Oxygen in Water Through Remote Sensing Techniques - Mr. Arthur W. Dybdahl, OEGC, National Field Investigation Center-Denver
- A Search for Environmental Problems of the Future - Messrs. James E. Flynn, Arthur A. Levin, Battelle Memorial Institute and Dr. James R. Hibbs, EPA, OR&D

2:40 p.m. - 3:00 p.m. Coffee Break

IX. 3:00 p.m. - 4:45 p.m. - Environmental Monitoring Requirements

Mr. C. E. James, Office of Monitoring Systems, OR&D

- Plans, Programs and Requirements
- Region I - Dr. Helen McCammon, OR&D
- Region II - Mr. Francis P. Nixon, S&A Division
- Region III - Mr. Edward Cohen, OR&D
- Region IV - Mr. Edmond T. Lomasney, OR&D
- Region V - Mr. Clifford Risley, Jr., OR&D
- Region VI - Mr. Ray Lozano, S&A Division
- Region VII - Mr. Alex Alexander, OR&D
- Region VIII - Mr. Russell W. Fitch, OR&D
- Region IX - Dr. Douglas Longwell, S&A Division
- Region X - Mr. Ralph R. Bauer, S&D Division
- NFIC- Denver - Mr. Arthur W. Dybdahl, OEGC, Denver

X. 4:45 p.m. - 5:15 p.m. - Comments

Mr. John D. Koutsandreas, Office of Monitoring Systems, OR&D

- National Academy of Sciences - CORSPERS, Environmental Measurement Overview and Assessments, Panel Conference Comments - Dr. Virginia L. Printice
- Closing Remarks - Mr. John D. Koutsandreas

5:15 p.m. - 5:45 p.m. - NERC-Las Vegas Tours

Laser Demonstration - Dr. S. Harvey Melfi

Imagery Processing and Interpretation Lab Tour - Mr. Albert E. Pressman and Mr. Leslie M. Dunn

CONFERENCE KEY NOTE ADDRESS

BY

WILLIS B. FOSTER

DEPUTY ASSISTANT ADMINISTRATOR FOR
MONITORING SYSTEMS
ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

It has been about two years since I last addressed many of you in this same auditorium. At that time, we endeavored to gain a better understanding of how sensing technology, both remote and in-situ, could be directed toward meeting the needs of the EPA Regional Offices, the State environmental agencies, and the environmental agencies' municipalities. Although the resources have been insufficient to allow us to realize many of our objectives, through the efforts of many here in this auditorium, we have been able to a degree to demonstrate the potential of this valuable technology. It is anticipated that through demonstration and operational application, remote sensors will continue to play an increasingly significant role in the monitoring program of our agency -- as well as at the State and local level.

It is encouraging to learn that recently the program offices within EPA are increasing the application of remote sensor data for their requirements. One specific example, worthy of mention, is the Reserve Mining case where remote sensor data were successfully introduced by both sides and accepted by the court as evidence. Here the Office of Enforcement and General Counsel acquired imagery from high altitude aircraft and the ERTS satellite. These data were effectively utilized in a court exhibit to show the sediment outfall from Reserve Mining operation, and its transport across the west end of Lake Superior. I understand you will hear more of this effort during the conference.

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Other Federal agencies have also been helpful in promoting remote sensor technology in the Environmental Protection Agency, as is evidenced by the scientists and engineers from other agencies on the agenda and in the audience today. However, an all-government team is not enough. The universities and industry must also play an important part in research and development. It will be refreshing and a privilege to hear some of their viewpoints during this conference.

Although research and development is essential and is being promoted by this Agency, we are often under the gun to show immediate results and operational applications. This stems from the regulatory nature of the Agency where the primary emphasis is on enforcement of environmental quality standards. We often take action using techniques that are neither thoroughly proven nor standardized. Here again we look to the universities, industry, and other Federal agencies for sensor techniques under development which might be applied to our needs. Thus, the primary theme for our conference this year is one of "applications." I understand that in the next two days the speakers will share with us those methods and techniques which could be effectively utilized right now, and which are potential standard methods.

The promulgation of standards and regulations is an important aspect of the EPA program. It has been identified as a specific management objective for FY 1974 and, therefore, a major focus of the Administrator's personal attention. The magnitude of our task in monitoring the nation's environmental quality is tremendous -- it's going to require something more than the proven techniques. To meet our requirements to enforce standards and regulations, we must use new remote monitoring instrumentation. There are a total of 135 known standards, regulations and regional reports to Congress which the Agency is currently developing. We are pursuing automated in-situ or remote sensing techniques to supplement the older, accepted, time-consuming laboratory techniques.

Over 32,000 major air pollution point sources must be brought into compliance with final emission limitations as prescribed in approved state implementation plans. Achievement of this objective will require a vigorous program of air quality monitoring and enforcement to insure performance by uncooperative polluters. Here again, remote sensing is expected to play a prominent role.

Under authority of the new environmental laws, EPA has a mandate to encourage the modification of certain kinds of land use which aggravate air and water pollution. The nation needs a comprehensive land use act that will embrace the land aspects of all environmental problems -- air and water pollution, noise abatement, waste disposal, management of toxic substances, outdoor recreation, urban planning, population dispersal and control of population growth itself. Unlike air and water pollution, the results of land misuse are often irreversible; we must live with it for generations and in some cases forever. Overhead monitoring can provide the regions and states with an accurate inventory of their land assets so that they are in a better position to assure that growth does not destroy cultural, historical and aesthetic values or unique ecological systems.

Through permits, we are responsible for controlling the discharge of pollutants from point sources into the nation's waterways, under the Federal Water Pollution Control Act of 1972. This requires regulating 40,000 of the nation's 300,000 industrial water users and nearly 13,000 municipal sewage treatment plants. The periodic monitoring and reporting of discharges calls for efficient, accurate and timely monitoring -- automated in-situ and remote monitoring technology may offer a practicable sollution. But that's enough for pollution as such.

With less than six percent of the world's population, the United States consumed one-third of the globe's energy production in 1972. Our energy demand is projected to more than double by the year 2,000. In the meantime, the United States is approaching the end of its supply of cheap fossil fuel reserves, with little prospect of new power sources for the next fifteen years. As you are aware, the crisis was caused by several complex and interacting factors, including increased environmental consciousness, which forced cutbacks in the use of certain high pollution fuels and stymied efforts to construct a number of nuclear power plants. You are all well aware of the delays resulting from fear of damage to the environment resulting from construction of a pipeline carrying 170° oil across tundra and permafrost regions. Energy is a vital component of environmental rehabilitation as well as America's prosperity. The problem is whether reasonable energy demands can be met without harming the environment. Among the EPA energy objectives are included the promotion of efficiency and conservation; and in the production of energy -- we're responsible for environmental assessments of the entire energy chain -- extraction, processing, transportation and utilization. Remote sensing can and should play an instrumental role in monitoring this entire energy chain.

Successful nations are those that are able to respond to challenge and to change when circumstances and opportunities require change. The demands on our natural resources have grown commensurate with our growth in population, industrial capacity and increased prosperity. All these indices reflect the constant upward thrust in the American standard of living. But, in order to maintain our standard of living and maintain a pleasant, clean environment, a high degree of technological sophistication will be required.

We look to you scientists and engineers gathered at this Second Environmental Quality Sensor Conference to help provide some of the advanced technology for monitoring the quality of the environment and to provide the capability for assuring its protection and enhancement -- I wish you success in this meeting.

SESSION I

NERC-LAS VEGAS PROGRAMS

CHAIRMAN
MR. DONALD T. WRUBLE
NERC-LAS VEGAS

INTEGRATED REMOTE SENSING SYSTEM

by
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LAS VEGAS, NEVADA 89114

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INTEGRATED REMOTE SENSING SYSTEM

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ABSTRACT

An aerial remote sensing system is being implemented to help meet the research, surveillance and enforcement requirements of the various offices of the U.S. Environmental Protection Agency (EPA). An integral part of the system is a computerized data acquisition system which allows for partial automatic data processing of aerial thermal mapping and multispectral measurements. Simultaneous photographic coverage is time-related to radiometric measurement for detailed analysis. A video system which records analog data on magnetic tape provides the near real-time interpretation necessary to respond to emergency situations.

This integrated remote sensing system is an attempt to meet specific monitoring requirements and provide the EPA with a fully operational capability. Anticipated use of this data collection system to meet specific EPA objectives in oil and hazardous material spill emergencies, outfall detection and inventory, runoff models development for agricultural pesticides, and other airborne monitoring investigations is discussed. Types of data collected and final results of typical projects are shown.

SECTION I

INTRODUCTION

The Environmental Protection Agency (EPA) was established by the President as a regulatory agency to safeguard our nation's air, water, and land resources for present and future generations. In order for the EPA to accomplish this task, it must establish a comprehensive and effective program for monitoring the environment. EPA has the dual responsibility for developing techniques for collecting environmental quality data and the utilization of that data for planning and regulatory purposes. In accomplishing these objectives, EPA utilizes new developments from other agencies such as NASA.

The National Environmental Research Center in Las Vegas, Nevada, (NERC-Las Vegas) has been charged with the responsibility for developing applicable monitoring techniques and programs and providing demonstration studies to assess their effectiveness. To meet this responsibility the Monitoring Operations Laboratory, Imagery Acquisition and Interpretation Branch, is developing an integrated system for the collection, processing, interpretation and reporting of remote sensing data. While remote sensing techniques have limitations, the synoptic nature of these measurements and the ability to provide needed information rapidly over large areas with a minimum number of ground monitoring stations can have great value in augmenting Regional monitoring programs.

Aircraft, sensors, processing and reduction equipment, and data analysis methods have been selected to best serve a wide range of environmental problem solving tasks. The appendices provide detailed information on major equipment and instrumentation which comprise the integrated remote sensing systems. Listed below are five areas we are pursuing that address the needs submitted by the EPA regional offices, Office of Enforcement and General Counsel, and the Division of Oil and Hazardous Materials.

1. Outfall Detection, Location, and Analysis

   This program will develop a catalogue of water outfall characteristics (relative to aerial monitoring) for the more significant categories of outfalls recommended by all EPA Regions. Based on this first phase, optimum aerial remote sensing techniques from existing state-of-the-art capabilities at NERC-Las Vegas will be field tested at selected sites throughout the country. Data will be analyzed and a manual prepared showing ground and airborne coverage of the outfalls. Emphasis will be placed on identification of unique characteristics of outfalls with existing techniques and defining future research and developmental needs in this area. Table 1 is a list of outfalls which were submitted for detailed study by the EPA regional offices.

2. Oil Spill Damage Assessment and Documentation

   This program involves the management of aerial surveillance responses to major incidents of oil or hazardous materials spills. Six contractors have entered into basic ordering

Table 1. Outfall Categories for Investigation by Remote Sensing

	STANDARD INDUSTRIAL CLASSIFICATION (SIC)	SIC #
1.	Feed Lots	0211
2.	Metal Mining	1011
3.	Bituminous Coal and Lignite Mining	1211
4.	Crude Petroleum and Natural Gas (Extraction)	1311
5.	Beet Sugar	2063
6.	Pulp Mills	2421
7.	Paper Mills	2600
8.	Chemical and Allied Products	2800
9.	Industrial Inorganic Chemicals	2810
10.	Plastics Materials, Synthetic Resins and Nonvulcanizable Elastomers	2821
11.	Petroleum Refining	2911
12.	Blast Furnaces (incl. coke ovens) Steel Works and Rolling Mills	3312
13.	Primary Metal Industries and Fabricated Metal Products	3352
14.	Telephone and Telegraph Apparatus	3661
15.	Electric Services	4910
16.	Municipal Outfalls	4952
17.	Ocean Dumping	4953

agreements (BOA) with NERC-Las Vegas to provide remote sensing services for emergency spills too distant for a timely response from NERC-Las Vegas. Figure 1 describes the organization interactions and information channels for a BOA activation.

Subsequent efforts will include the investigation of systems designed for increased resolution and accuracy and the implementation of better methods of aerial surveillance reaction to emergency spills.

3. Agricultural Chemical Run-Off Model

Efforts in the remote sensing portion of this program will be to provide certain quantitative terrain parameters which can be inserted into mathematical models of river basins. The parameters of immediate study will be identification of crop type, delineation of land cover, drainage patterns, surface radiometric temperature, topographic slope, soil type, and conservation practices. Following initial flights over small instrumented test plots, a large scale survey of an entire river basin may be undertaken.

4. Non-Point Source Water Pollution Monitoring Approaches and Techniques

Identification and description of the most effective approaches for characterization of each category of non-point source pollution will be accomplished through intensive literature review and contact with Agency personnel engaged in assessing such sources. A report describing applicable non-point source water pollution monitoring approaches and techniques, (both contact and remote) based on the current state-of-the-art, will be generated. Anticipated coordination with the Pollutant Fate Research Program at the Southeast Environmental Research Laboratory will aid in the selection of procedures to calibrate and validate mathematical models for estimating pollution loads from non-point sources.

5. Technical Assistance Program

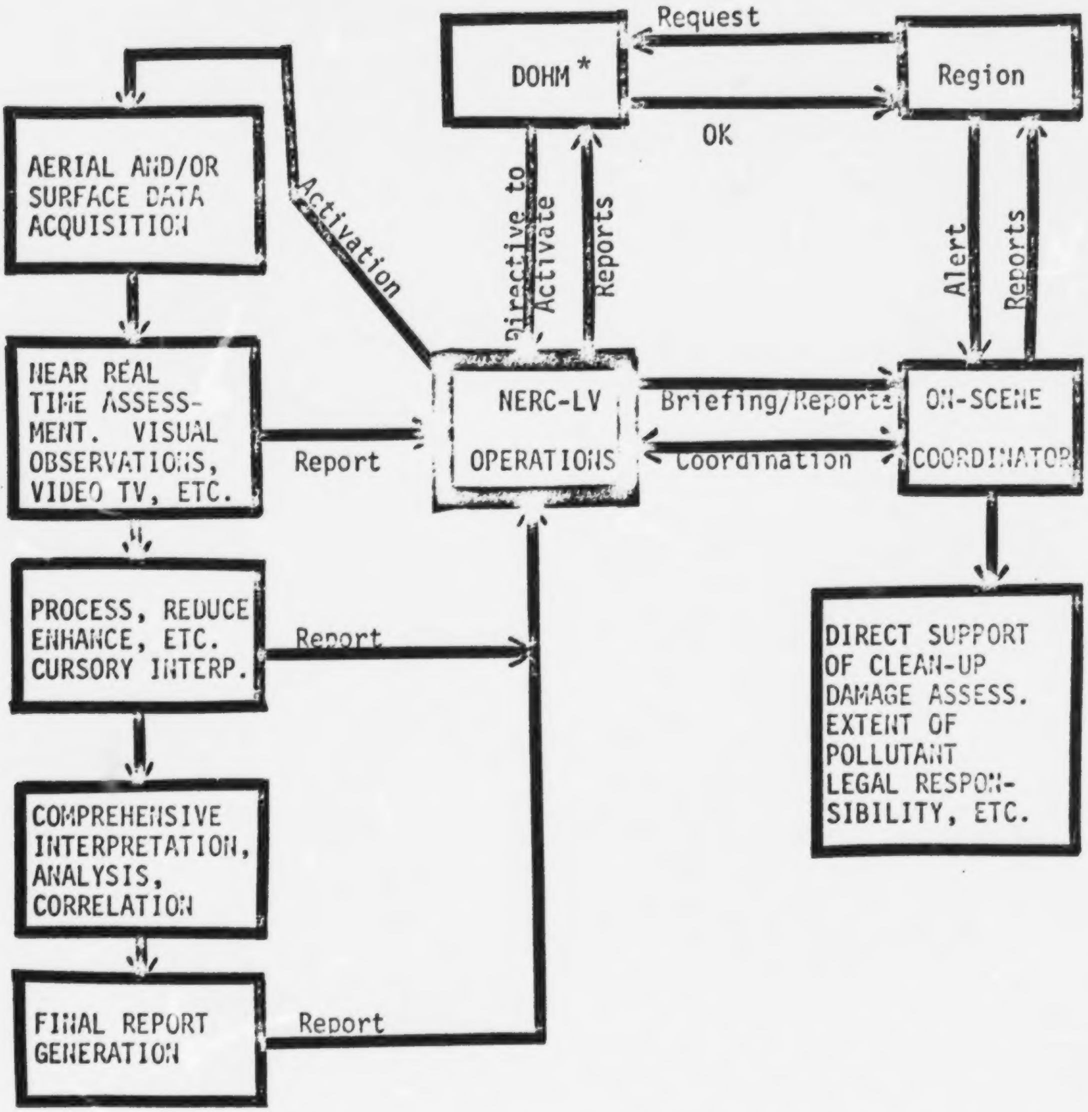
This program consists of relatively short response projects to meet immediate Regional needs. In practice, NERC-Las Vegas is requested to collect and analyze aerial remote sensor data to be used by the Region in support of an operational objective. Examples of these include outfall inventories and documentation of spillage from waste pits. Results are delivered to the Regions in the form of annotated data displays, raw data with location indexes, isothermal contour maps, or final interpretation reports.

The goal of NERC-Las Vegas under this program is to provide Regions with useful information within 45 days of notification; 15 days to collect the data and 30 days for analysis and reporting. We are getting closer to accomplishing this goal as the program obtains the necessary manpower and other resources.

Figures 2 through 5 illustrate a typical set of display boards; these were prepared for Region IX. Figure 2 is a photomosaic showing a sediment plume offshore at Santa Monica, California. Figure 3 was made in an attempt to track the sediment inland to its source. Figure 4 spotlights the construction activity which was believed to be the cause of this sediment entering the Bay. Figure 5 is an oblique view facing south along the California coastline at Moss Landing approximately 25 miles south of Santa Cruz. Shown are two facilities of interest to EPA in our routine surveillance activities under the national discharge permit program. Two power plants are located at 'B' and a facility engaged in the extraction of magnesium from the sea is shown at 'A'. In connection with this program stack emissions such as that evident at (B), and outfalls into streams seen at (3) and into bays (2) are monitored and documented. Number (1) is believed to be the surface manifestation of a newly buried outfall extending offshore. It will be investigated further.

FIGURE 1

QUICK RESPONSE OPERATIONAL REMOTE SENSING SYSTEM


DOHM *
Request
Region
OK
AERIAL AND/OR SURFACE DATA ACQUISITION
Activation
Directive to Activate
Reports
Alert
Reports
NEAR REAL TIME ASSESSMENT. VISUAL OBSERVATIONS, VIDEO TV, ETC.
Report
NERC-LV OPERATIONS
Briefing/Reports
Coordination
ON-SCENE COORDINATOR
PROCESS, REDUCE ENHANCE, ETC. CURSORY INTERP.
Report
DIRECT SUPPORT OF CLEAN-UP DAMAGE ASSESS. EXTENT OF POLLUTANT LEGAL RESPONSIBILITY, ETC.
COMPREHENSIVE INTERPRETATION, ANALYSIS, CORRELATION
FINAL REPORT GENERATION
Report

*Division of Oil and Hazardous Materials

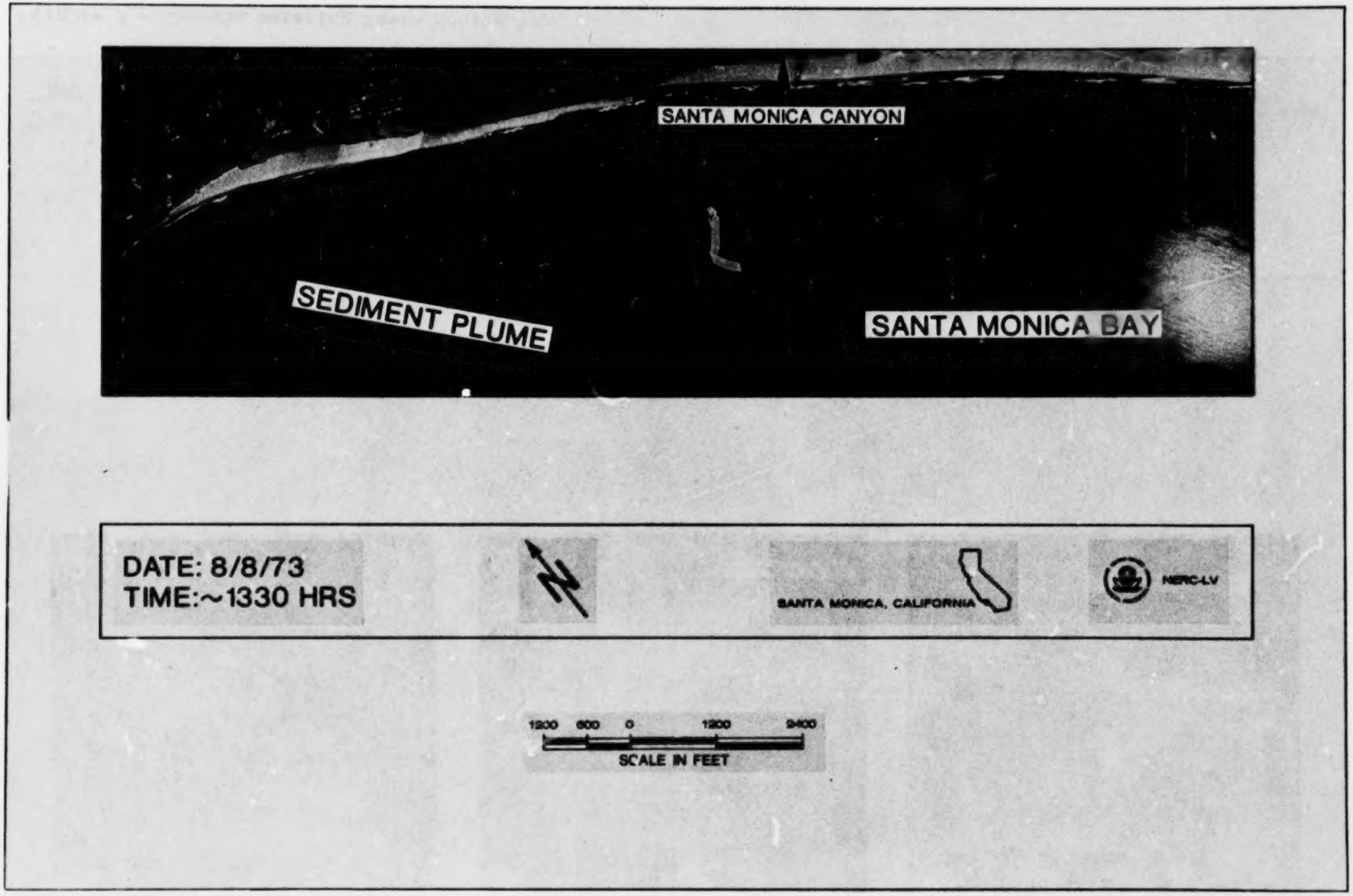
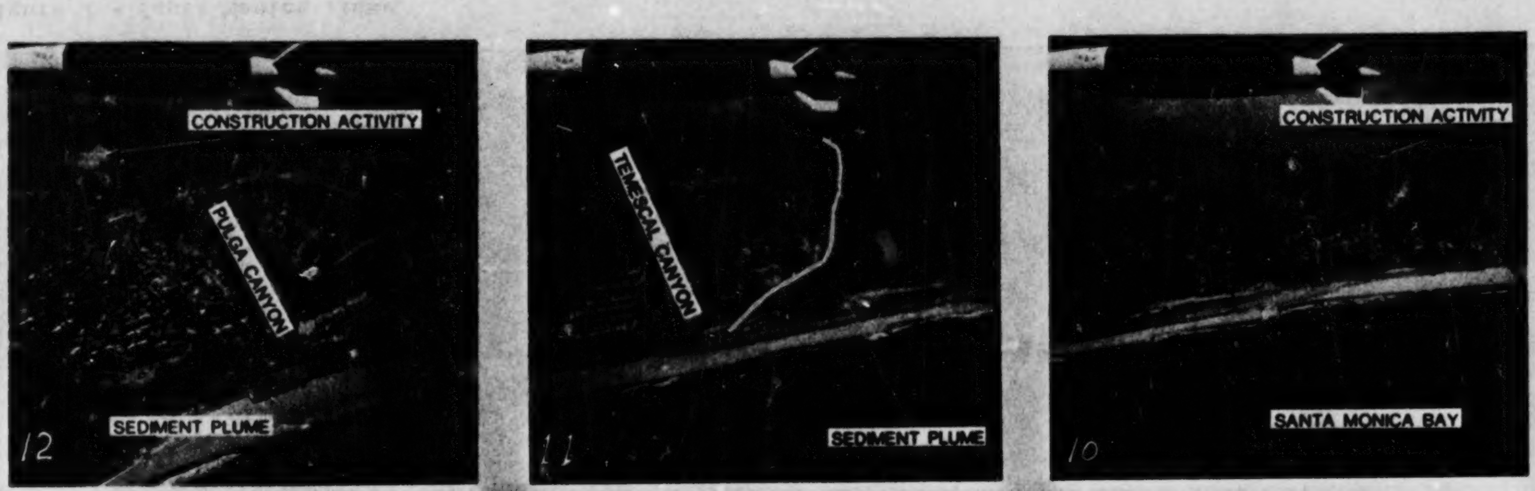


Figure 2 - Santa Monica Plume



FACING NORTHEAST

DATE: 8/8/73
TIME:~1330 HRS

SANTA MONICA, CALIFORNIA

NERC-LV

Figure 3 - Canyons entering Santa Monica Bay

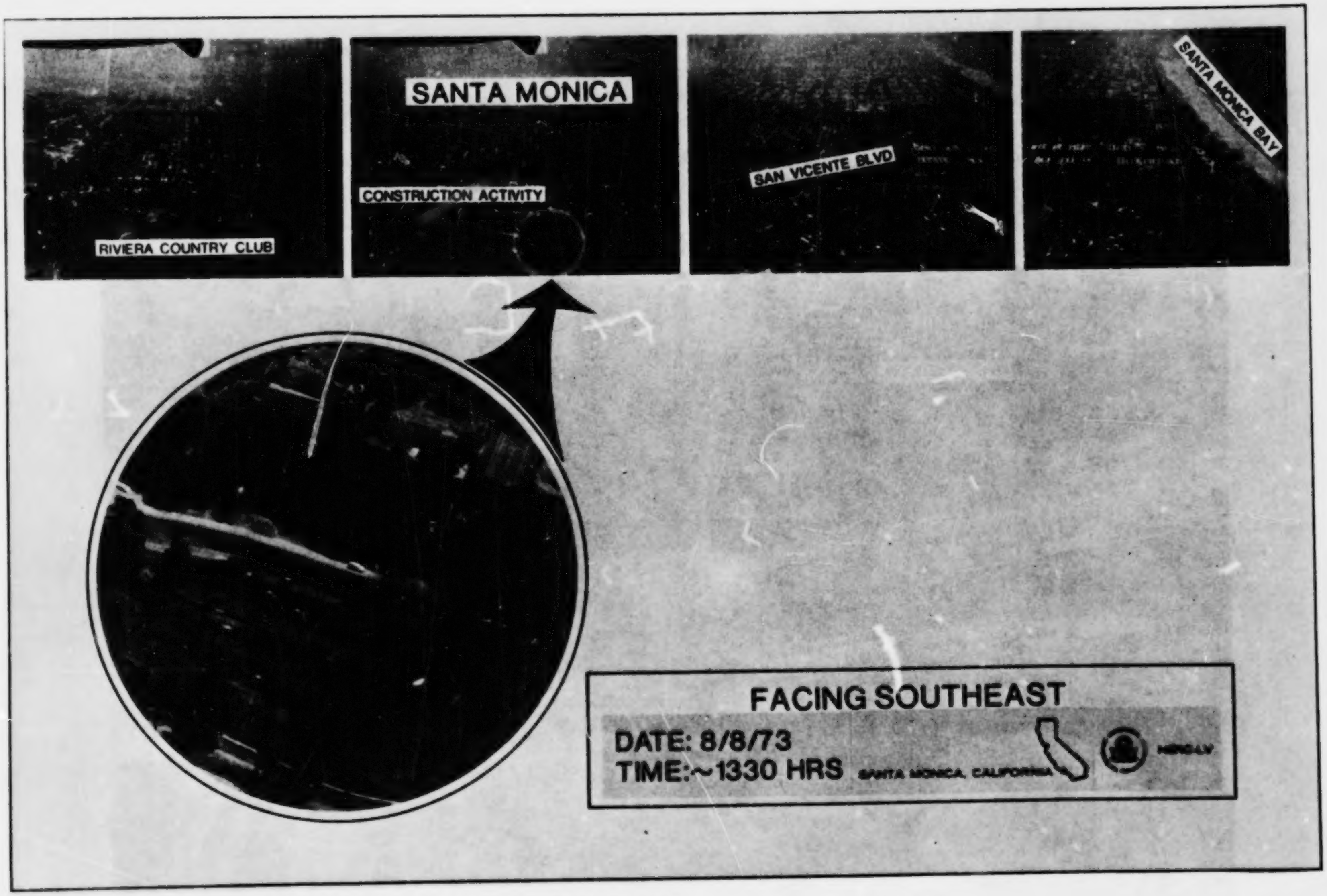


Figure 4 - Construction activity in canyon entering into Santa Monica bay.

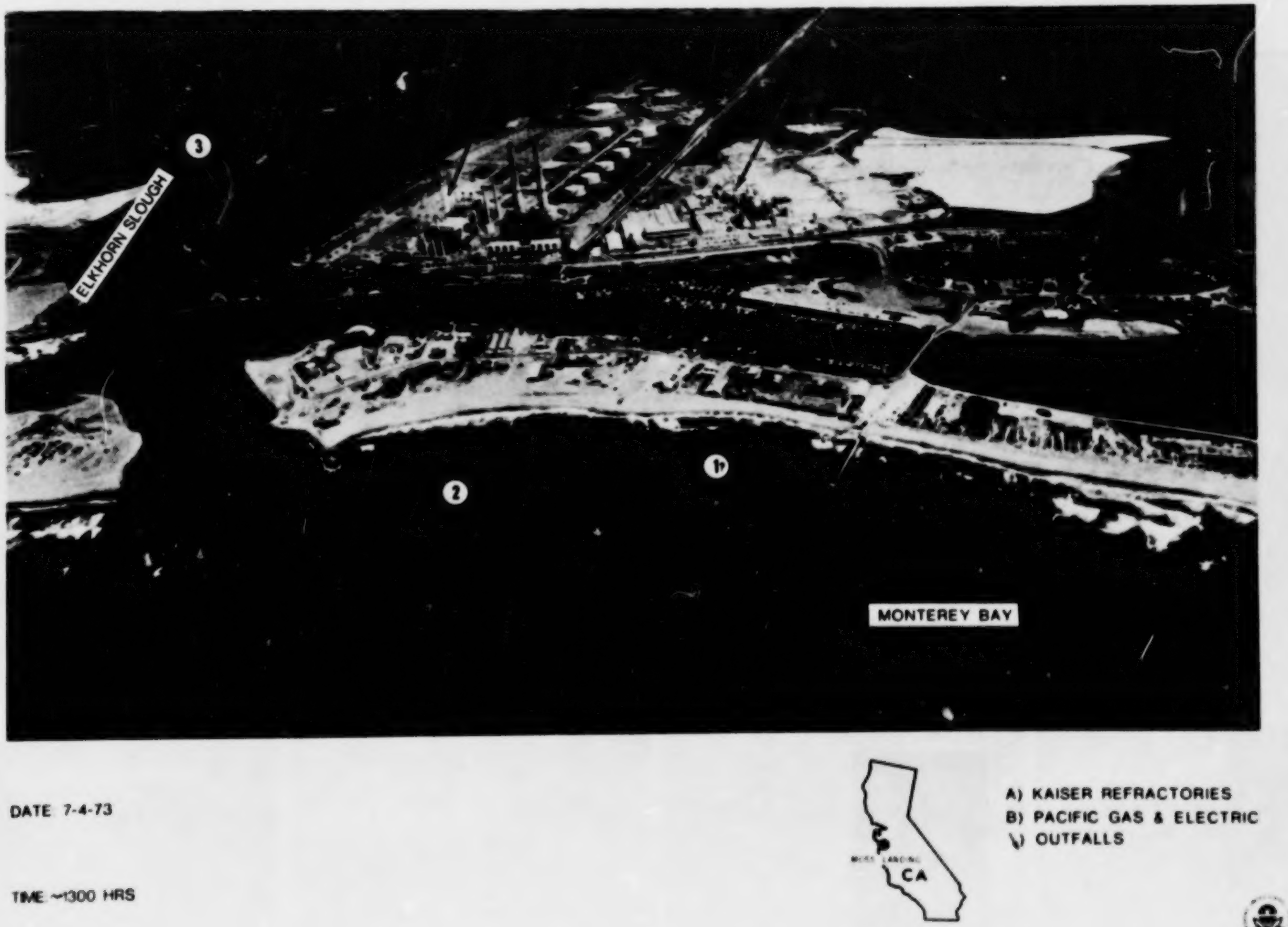


Figure 5 - Outfall discharges in Monterey Bay

SECTION II

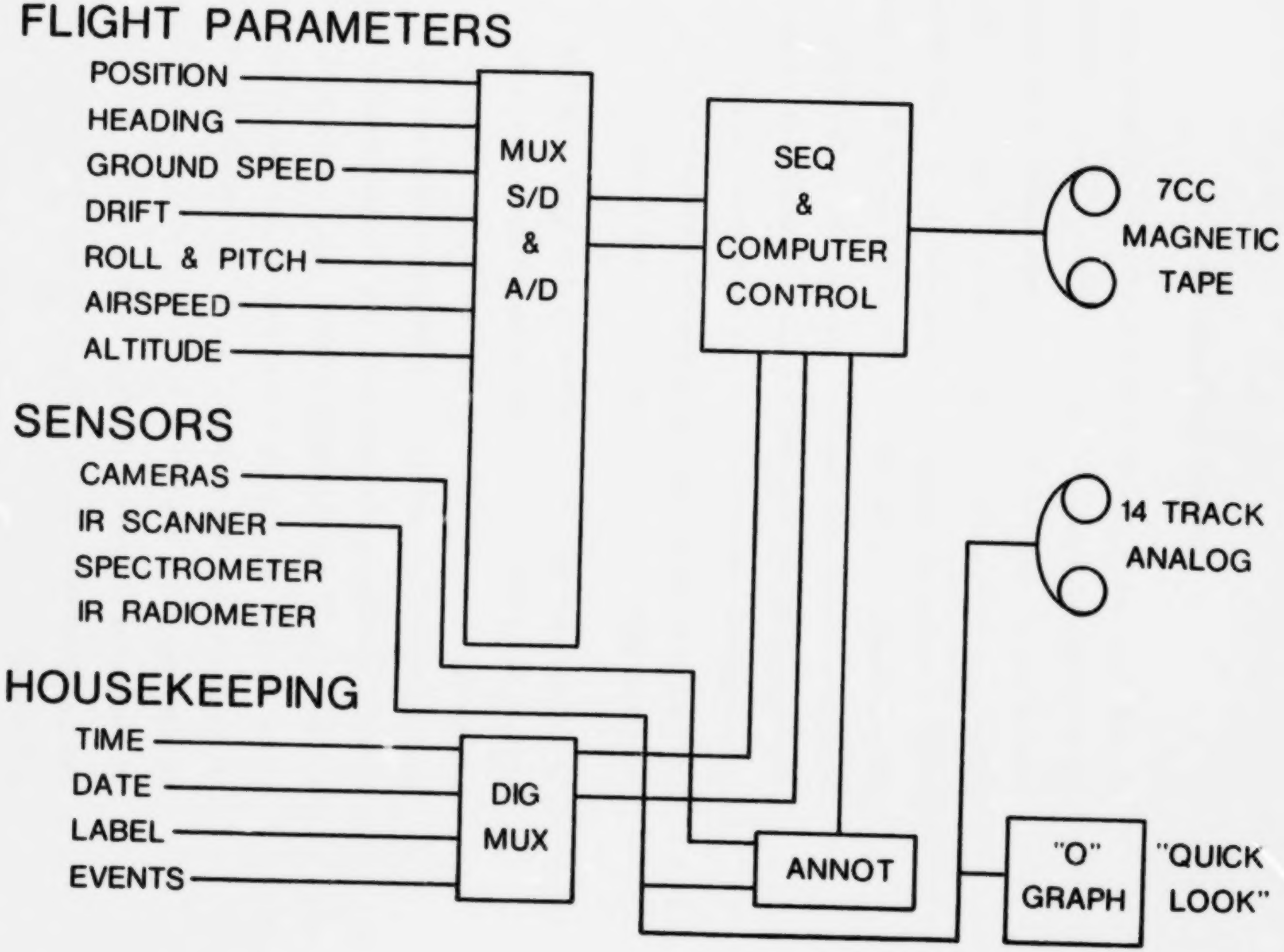
AIRBORNE DATA ACQUISITION

The basic design for our data acquisition system is oriented toward operational remote sensing techniques development. Sensors selected for incorporation into our data acquisition system consist primarily of off-the-shelf instrumentation that requires only interfacing to produce an operationally integrated system. This system, shown in Figure 6, is designed to minimize the manual data processing required to produce final results. This has been accomplished by cross correlating all data with a common time base; even the non-digital instrumentation such as the camera systems are annotated with a digital time code so that the photographs can easily be cross referenced with information collected by other sensors.

An integral part of the airborne data acquisition system is a computer which formats all flight parameters for automatic data processing. Time, position, heading, ground speed, drift, roll, pitch, airspeed, and altitude are digitally recorded and multiplexed on 7-track computer-compatible tape. Camera exposure pulses and spectrometer and IR radiometer(PRT-5) signals are also recorded on the 7-track tape. The IR scanner data are recorded on an analog 14-track wide-band tape recorder. All analog information collected is displayed in the aircraft in real time on a strip chart recorder to insure that all sensors are functioning properly. The strip chart also serves as an aid in the screening of data for initial processing.

Figure 6

AIRBORNE DATA ACQUISITION SYSTEM



SECTION III

DATA PROCESSING

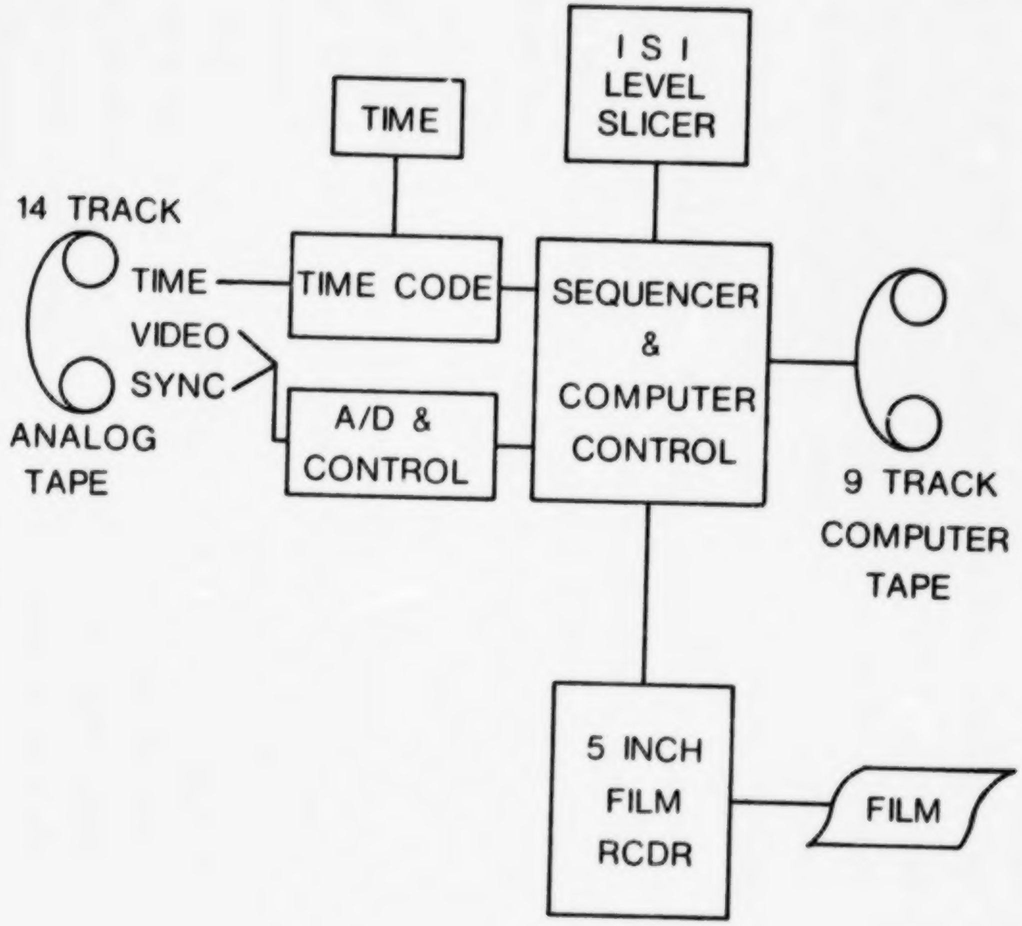
After the information is collected and recorded, the system is designed for preprocessing at a ground data interpretation station which consists of a 14-track wide-band tape playback recorder, a high speed analog-to-digital converter, a computer, a 5-inch film recorder, an image enhancement system, a scan converter, and a 9-track computer-compatible tape recorder. Figure 7 is a schematic diagram of the ground interpretation station.

The IR scanner output recorded on the 14-track tape is digitized and stored in the buffer memory of the computer. A computer program then thins the data by predetermined programming into elementary data points. The information is then transferred to a 9-track computer-compatible tape.

For applications requiring high spatial resolution, such as detection of small outfalls, the thermal infrared imagery is recorded on 5-inch black and white film from the original 14-track tape recording. No data thinning is undertaken. The scan conversion system allows the operator to view the tape on a TV monitor and select those portions which contain anomalies of interest. An additional analysis option is to display thermal levels on the infrared imagery as discrete colors for quantification of temperature zones in thermal plumes. The 7- and 9-track tapes then go to the central computer facility where the data are processed in the CDC 6400. From the information on the 9-track tape an atmospheric effects table is generated which corrects all data

Figure 7

GROUND DATA INTERPRETATION STATION

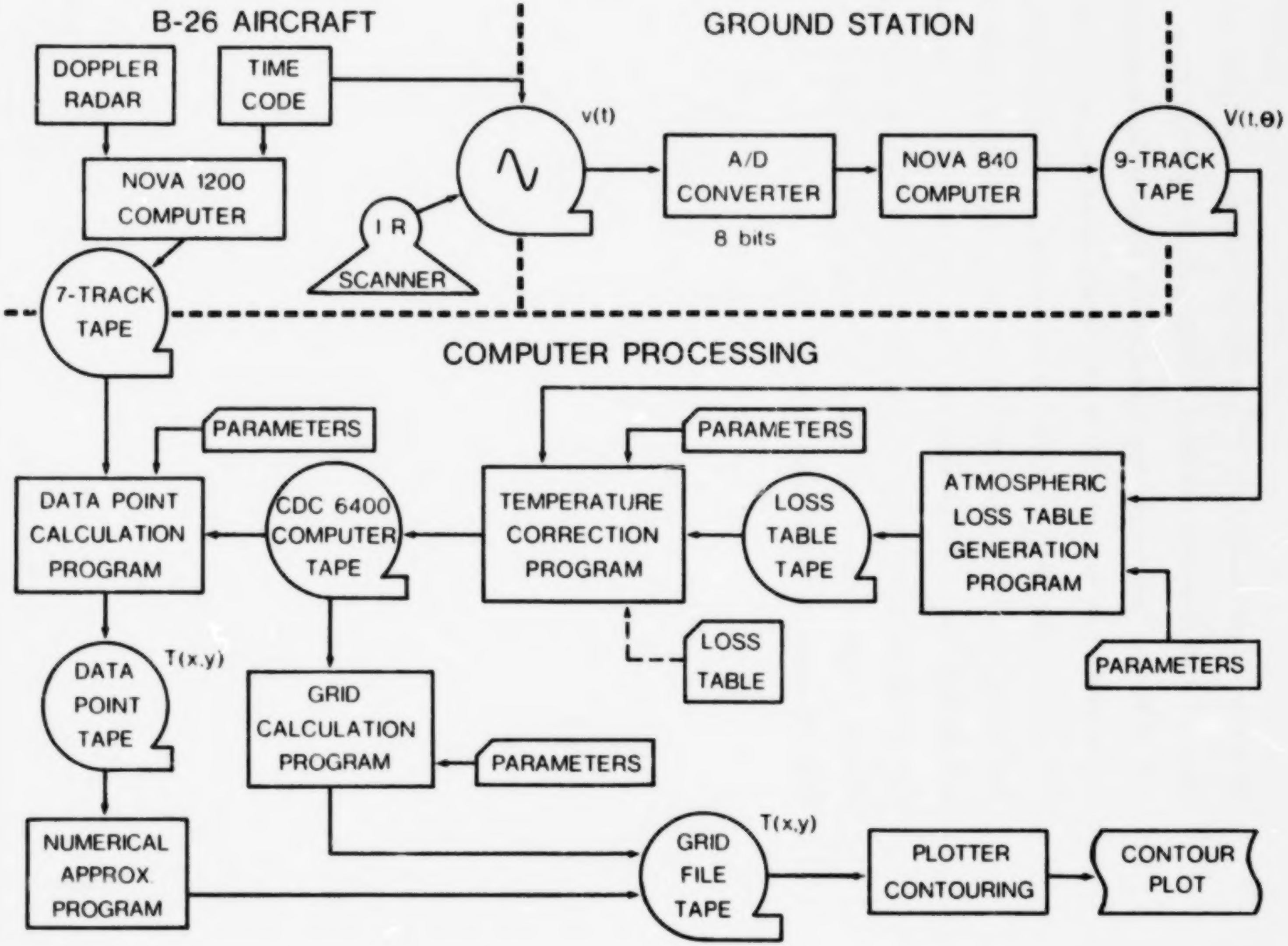


TAPE TO TAPE/TAPE TO FILM

points to ground datum. The IR scanner has been d.c. restored and equipped with detectors having increased sensitivities and black body reference sources (so that quantitative temperature measurements can be made). We hope to achieve an overall system accuracy of about $1/2^{\circ}$ C after atmospheric effects are considered. Because of the scan angle geometry, it is also necessary to make a rectilinear correction of each scan line. The geometrically and radiometrically corrected data are then plotted as an isothermal contour map on a 25-inch drum plotter. A schematic of the data collecting, processing, and contour plotting system is illustrated in Figure 8.

Figure 8

CONTOUR PLOTTING SYSTEM FOR I R SCANNER DATA



SECTION IV
AIRCRAFT

A Monarch B-26 is used by NERC-Las Vegas to fly the missions previously described. This aircraft, in our estimation, represents one of the best trade-offs of financial and operational factors that was commercially available. This aircraft satisfied the requirement for access to all equipment in flight to make equipment adjustments, change film and filters, and monitor acquisition of all data at a central console. The aircraft also has the speed and altitude capabilities which are dictated by our need to respond to emergency oil spills for the Division of Oil and Hazardous Material. Additional characteristics and specifications of the B-26 are found in Appendix A.

SECTION V

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APPENDIX A

AIRCRAFT

B-26 SPECIFICATIONS

Wing Span	70 feet
Length	54 feet
Height	18 feet
Maximum Gross Weight	34,000 pounds
Empty Weight	21,139 pounds
Landing Weight	31,000 pounds
Engines - two	R-2800-71 2000 HP
Fuel	800 gallons
Cruise Speed	240 knots
Landing Speed	100 knots
Altitude	Up to 25,000 feet
VFR Range (with reserve)	1200 nm
Flight Crew	2
Sensor Operators	2
Navigation Equipment	Includes DOPPLER, VOR, ADF, DME
Communications Equipment	Includes VHF, UHF, and ADF
Control Equipment	Includes Flight Director System and Autopilot

APPENDIX B

DATA COLLECTION SYSTEM

1. Infrared Scanner (RS-310)

Field of View (Degrees)	90
Resolution (milliradians)	1.5
V/H Range (Radians/Second)	.03 to 0.3
Scanner RPM	3000 (200 Scans/Sec)
Noise Equivalent Temperature, Large Target (Degrees C Referenced to 300° K Background)	0.20 (InSb) 0.12 (GeHg)
Wavelength Region (Microns)	.3 - 14 (Optics Capability)
Collecting Aperture (inches^2)	6.35
Number of Units in System	5
Size and Weights of Units	
Scanner/Recorder (Unit 1)	16.50" L x 14.50" W x 15.00" H 55 Lbs. (without magazine
Control Panel (Unit 2)	5.75" L x 5.32" W x 3.00" H 2.7 lbs.
Power Supply (Unit 3)	13.00" L x 8.50" W x 3.75" H 11.4 lbs.
Film Magazine (Unit 4)	6.40" L x 5.925" W x 8.45" H 9.0 lbs (without film)
Compressor (Unit 5) (when closed cycle cooling)	10.50" L x 8.25" W x 10.50" H 19.0 lbs.

APPENDIX B (Cont.)

Characteristic	Specification
Ambient Temperature Limitations	0° - 100° F
Altitude Limitations	0 - 10,000 feet
Input Power Requirements:	
AC Voltage	117 Vac, 400 Hz, 3 Phase
AC Power	45 VA
DC Voltage	28 Vdc
DC Power	135 Watts Run 160 Watts Start
Noise Equivalent Temperature (NET)	
8 - 14 pm	
1.0 mrad	0.15° C
3.0 mrad	0.07° C
10.0 mrad	0.02° C
3 - 5 pm	
1.5 mrad	0.20° C
3.0 mrad	0.10° C
Number of Dectectors	2
Types of Dectectors	
8 - 14 pm	Mercury-Cadmium Telluride (HgCdTe)
3 - 5 pm	Indium Antimonide (InSb)
Detector Cooling	Open-cycle system (Dewar) operating at 77° K
Stabilization	Roll ±10
Recording Format	2.30 in.

APPENDIX B (Cont.)

2. Aerial Camera (KA-76)

Primary Use	Day/Night Reconnaissance
Film Information	
Format (in.)	4.5 x 4.5
Width (in.)	5
Length (ft.)	250/100
Frames (per roll)	600/250
Magazine	Cassette
FMC Rate (ips)	0.15 - 10.8

Optics					
Focal Length (in.)	1.75	3	6	6	12
Max Apt	5.6	4.5	2.8	1.5	3.5
Angular Coverage ( )	105°	74°	41°	41°	21°

Resolution (L/mm) (TC 1000:1)	35 pan-X 40 plus-X 25 IR 40 pan-X
Shutter Speed	1/60 - 1/3000
Shutter Type	Focal Plane
Remarks	Automatic Exposure Control

3. Scanning Spectrometer

Component	Function
Rotating Filter Wheel	Selectable Discrete Bandpass Analysis
Filters	3400 - 9800 A°
Visible Region (4000-7000)A°	Circular variable
Nominal Half-band width	250 A°
Center Wavelengths (3400-7000)A°	@ 300 A° intervals
Center Wavelengths (7000-9800)A°	400 A° intervals

APPENDIX B (Cont.)

Component	Function
Detector, Silicor Photodiode, Extended UV Coverage	Photovoltaic
Telescope, 3-inch, f-3 Newtonian	Reflective, 2° f.o.v.
Control Electronics	SYNC and Output Selection

4. TV System

Component	Function
RCA SIC Camera PK 501	Flight Path Surveillance
Shibaden Vidicon Camera HV-155	Display Monitor Camera
Video Monitor RCA PM 9C	Equipment Operator Monitor
Video Monitor Shibaden 9 inch	Pilot Monitor
Video Tape Recorder Shibaden SV-510U	IR Video Recording
Special Effects Gen SE-101S	Mix 2 Camera Video
SYNC Generator SG 105-L	Video SYNC
TV Zoom Lens V5 x 20	Zoom Capability

APPENDIX C

DATA PROCESSING

Major Equipment	Function
Data General Nova 840 Computer, 16K Memory	Processing and Control
Phoenix 8BIT A to D Converter	Digitize IR Scanner Video Signal
Sangam 14 Channel Analog Record/Reproduce and Audio	IRIG Intermediate and Wide Band Group II Record and Reproduce and Annotation.
Shibaden Video Tape Record/ Playback	Quick Look Viewing and Data Screening and Selection
ISI Model VP-8 Image Analyzer	Assigned Color Imaging System and Level Slicing to Represent IR Imagery Thermal Levels

APPENDIX D

PHOTOGRAPHIC PROCESSING

Log-Etronics MK II R5B	Step and repeat contact printer with two times enlarging capability, equipped with automatic exposure and even tone printing.
Pako Processor 33	Modified to 3 step chemistry for processing color prints up to 16" wide at 72" per minute.
Kodak Versamat 1411 RT	Quick change kit was installed for processing both color positive and color negatives.
Log-Etronic SP 10/70 B	Continous contact strip printing with automatic exposure and even tone printing. Has capability of printing 60 f.p.m.
EN 6A2	Prints color and black/white film in rolls from 700 mm to 9½" width (mostly used for color film transparency).
Log-Etronic Enlarger E-10	Enlarger with automatic exposure control and even tone printing.
Robinson Copy Camera	Scaled reproduction of $\frac{1}{10,000}$" accuracy, for interpretation, photomosaic, and reports.
Miller Holzworth EN 46A Enlarger	Fixed ratio enlarger for enlarging 70 mm film four times.

AERIAL AIR POLLUTION SENSING TECHNIQUES

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ABSTRACT

A capability for aerial monitoring of air pollutants has been developed at the National Environmental Research Center at Las Vegas (NERC-LV). A comprehensive monitoring system incorporating measurement instrumentation for NO, NO_x, O_3, CO, non-methane hydrocarbons, sulfur gases, particle size, light scattering, temperature, dewpoint, and fluorescent particle tracer concentration has been developed and installed in a twin-engine helicopter for measurement of ambient levels over metropolitan Los Angeles. The system records its data on magnetic tape.

Available instrumentation suitable for aerial monitoring was surveyed, and components of the system were selected on the basis of seven criteria: resistance to vibration and stress, stability under variations of temperature and altitude, sensitivity, fast response time, low power consumption, size and weight, in order of decreasing importance. Commercially available analyzers have evolved sufficiently that satisfactory instruments for most of the listed parameters are now available. System components were tested for stability under varying altitude and temperature in an environmental chamber. Various navigational aids were evaluated as possible components of the system.

Mathematical techniques to compensate for instrument response time are available. The convolution integral technique appears to be the simplest in application.

AERIAL AIR POLLUTION SENSING TECHNIQUES

By Roy B. Evans

The Los Angeles Reactive Pollutant Program (LARPP), currently in progress, and the Regional Air Pollution Program (RAPS) both include important roles for airborne contact sensing of air pollutants. The LARPP is designed to compile a data base suitable for developing and validating mathematical models of air pollution photochemistry. The RAPS has the more ambitious goal of developing regional models which will deal with both photochemistry and dispersion of pollutants.

The LARPP is concerned with photochemical reactions within a parcel of air as it moves downwind. Air parcels are isolated and followed to measure pollutant concentrations within the parcels (NO, NO_2, CO, O_3, non-methane hydrocarbons, and particulates) from both airborne and ground-based sampling platforms. The LARPP aircraft are also measuring temperature, dewpoint and fluorescent particle concentrations. Ultra-violet radiation is being measured by ground-based stations throughout the Los Angeles basin. The product of this effort is a time history of vertical profiles of each of the pollutants being measured within the parcel.

The aerial monitoring requirements for the RAPS have not yet been defined in detail, but vertical profiles and horizontal cross-sections at relatively low altitudes above the RAPS St. Louis ground station network will be necessary. Sulfur gases will be of interest in St. Louis, in addition to those parameters presently being measured by the LARPP aircraft.

MONITORING PLATFORMS

The type of aircraft selected for monitoring platforms depends on several factors: the geographical area over which monitoring is to be performed, the required payload, electrical power required for monitoring instrumentation, the necessity for a crew to operate instrumentation, aircraft range and the desired monitoring airspeed.

The limiting consideration for both the LARPP and RAPS programs is the requirement to operate at low altitudes over urban areas. In the case of the LARPP, the air parcels to be sampled are identified with clusters of three tetroons, ballasted to attain a nominal altitude of about half of the inversion height (typically, a nominal ballast altitude of 500 feet). The sampling vehicle then executes square patterns about the centroid of the tetroon cluster at altitudes ranging from 200 feet up to the base of the inversion. The RAPS program is also expected to require operation at altitudes as low as 200 feet over urban St. Louis. Safety considerations and Federal Aviation Administration (FAA) restrictions essentially dictate the use of either twin-engine helicopters or some kind of lighter-than-air vehicle.

The instrument payload in the LARPP and RAPS aircraft amounts to approximately 1500 pounds, and the electrical power load is approximately 4 kilowatts. Two instrument men and a navigator are required in addition to the pilot.

A flight range of at least two hours is required. Both helicopters and lighter-than-air vehicles were investigated initially, but the lighter-than-air vehicles were quickly discarded. The payload of instruments and crew exceeds the capacity of available blimps, and blimps possess limited maneuverability. Operation of blimps at altitudes as low as 200 feet appears to be of questionable safety, and rental rates for blimps appear to be on the order of $2000/day.

There are two types of twin-engine helicopters available in the United States which satisfy the LARPP and RAPS requirements: The Bell 212 (military designation UH-1N) and the Sikorsky 58 (military H-34) modified to twin-turbine capability (58T). Both are capable of sustained flight with one engine, and both can carry useful loads of more than 2500 pounds. Both can provide up to 10 kilowatts of electrical power. The Bell 212 has a useful range of approximately 1 hour and 45 minutes, while the twin-turbine Sikorsky 58T has a range of approximately 2 hours and 15 minues. Rental rates for the Bell 212 are on the order of $20,000 per month plus $200 per hour, including fuel and pilot. Comparable rates presently quoted for the Sikorsky 58T are $14,000 per month and $150 per hour. The Sikorsky 58T has greater cabin space and is probably a more convenient flying laboratory. Two leased Bell 212 helicopters are presently in use in the LARPP, and their performance has been satisfactory, although the present instrumentation load uses nearly all of the available space.

INSTRUMENTATION

The most important considerations in selecting instruments for aerial monitoring of air pollutants at the present state of instrument development are stability under flight operating conditions and response time. Power requirements and weight are of less importance because suitable sampling platforms with more than enough electrical power and payload are available. The total altitude range in sampling for the LARPP is approximately 5000 feet (sea level to 5000 feet MSL).

and the same range is expected to be adequate in St. Louis. Ambient temperatures at which the instruments are to function range from 0°F. to 120°F. Vibrational stress in the helicopter environment is severe, although no measurements of stress were made in the Bell 212's presently in use. The constant sampling airspeed used in the LARPP is 60 knots, and an aircraft operating at this speed covers approximately one-fifth of a mile in 10 seconds. This means that an instrument having a 10-second lag time and a 10-second response time to 90% of full-scale will require a total of approximately 0.4 miles to respond to a step-function increase in concentration.

Table 1 lists the instrumentation selected for the LARPP/RAPS helicopters. All of these instruments, with the exception of the sulfur gas analyzer and the particle size analyzer, are presently in use in the LARPP.

Chemiluminescence analyzers were selected for measurement of NO and NO_x. These instruments depend on the chemiluminescence reaction of NO with ozone:

$$NO + O_3 \longrightarrow NO_2 + O_2 + h\nu$$

The emitted light is measured with a thermo-electrically-cooled photomultiplier tube. Total oxides of nitrogen (NO_x) are measured by first converting NO_2 to NO by passing the sample gas over heated (450°C.) molybdenum. NO_2 is obtained by subtraction: (NO_x) - (NO). There are several chemiluminescent NO-NO_x analyzers which are commercially available, but the TECO 14B (Thermo-Electron Corporation, Waltham, MA) was selected because the instrument uses a low-pressure (300-torr) reaction chamber and the sample flow is controlled with a critical orifice, making the instrument relatively altitude-insensitive.

Ozone is measured with an instrument which is dependent upon the chemiluminescent reaction of ozone with ethylene. Again, the light emitted by the reaction is measured with a photomultiplier tube. Of the several ozone analyzers commercially available, the REM Model 612 was selected because it utilizes critical orifice flow control and is stable under varying altitudes. The instrument also differs from others in utilizing electronic temperature drift compensation rather than thermo-electric cooling of the phototube.

Of the several non-dispersive infrared analyzers available, only the Andros is small enough to be conveniently used in the aircraft as a CO monitor. This instrument utilizes dual-isotope fluorescence and has better sensitivity and stability than conventional NDIR. It is subject to significant zero drift while in flight, however. The

Mine Safety Appliances (MSA) Model 11-2 non-methane hydrocarbon analyzer utilizes two parallel flame ionization detectors (FID) one of which is preceded by a catalytic srubber to remove hydrocarbons heavier than methane. One FID thus measures total hydrocarbons, the other methane, and electronic subtraction gives the difference. There was relatively little choice in the selection of this instrument, even though the two in the LARPP helicopters are essentially prototypes. This measurement technique is the only one available which yields continuous measurements of non-methane hydrocarbons, and the MSA instrument is the only one currently packaged in a form suitable for field use. The alternative was the use of a chromatograph-type instrument, such as the Bendix 8201, which yields measurements of grab samples collected about three minutes apart.

DATA RECORDING

Because of the number of parameter inputs and the total data volume expected for both the LARPP and the RAPS, recording of data either by hand or with strip-chart recorders would be too laborious to be depended upon for the data archive. A digital data acquisition system which records the data inputs directly in standard BCD code on magnetic tape was incorporated into the system. Both manual observations and strip charts are taken, but these serve primarily for debugging and quick-look purposes. A Monitor Labs Model 7200 Data Acquisition System was selected to record directly onto a Cipher Model 70 Magnetic Tape Deck. These components have been generally satisfactory, but the tape deck is sensitive to overheating and will not function at temperatures above 105°F.

ENVIRONMENTAL CHAMBER TESTING

One instrument of each type was tested in an environmental chamber to determine its response to varying temperatures and altitudes. Instrument span and zero drift were measured as functions of temperature and altitude (barometric pressure). The data obtained in these tests must receive further verification before publication, but the instruments selected seem to perform well under varying ambient conditions. Span drifts are less than 10% over the operating ranges of temperature and altitude. Zero drifts as functions of altitude are negligible, and zero drifts as functions of temperature depend on the instrument type: the O_3 instrument appears to experience a zero shift of as much as 2 pphm out of 200 pphm full-scale; the NO and NO_x exhibit drifts of as much as 0.1 ppm at the upper end of the ambient temperature range, around 95°F ambient. At the same ambient temperature, CO drift of about 1 to 2 ppm out of 20 ppm full-scale is experienced.

CALIBRATION

NO, NO_x, O_3, CO and non-methane hydrocarbon analyzers receive a daily zero and single-point span calibration. Logs are kept of instrument drift and mechanical problems. In addition to these routine and rather ordinary procedures, instrument zero levels are measured in flight during each data gathering mission at approximately 45-minute intervals. Measured zero drift can then be subtracted from the recorded levels.

SUMMARY

The state of air pollution instrumentation now permits the fabrication of an aerial air pollution monitoring system to measure concentrations of NO, NO_x, O_3, CO, non-methane hydrocarbons, and other parameters from an aerial sampling platform. Special considerations must be given to temperature and altitude stability in the selection of this instrumentation.

Mention of trade names or commercial products in this report does not constitute an endorsement or recommendation for use by the Environmental Protection Agency.

Parameter	Measurement Method	Instrument Manufacturer/Model	Instrument Ranges	Minimum Detectable Concentration	Lag Time & Response Time	# of Digital Characters in Magnetic Tape Output	Calibration Method	Calibration Concentration	Sampling Flow Rate	Warm-Up Time
Fluorescent Part.	Fluorescence	Mee Industries/110	Continuous, 1, 2, 5, and 10 second intervals		250 ms RT per particle	4	Zero Output for zero source		.75 l./sec	<30 sec.
Particles > .3 μm	Individual Particle Counter	Royco/220	10 channels			20	Internal calibration or latex particles of known size		.1 ft^3/min	<30 sec
Visibility	light scattering	MRI/1550B	Three Ranges	b_{scat} - .1	Variable R.T. .1 - 200 sec.	6	Internal calibration or Freon 12	Pure Freon	0 ft^3/min	15 minutes when relative humidity > 60%
NO	Chemiluminescent	Thermo Electron Corp./14B	.05, .1, .25, .5, 1.0, 2.5, 5.0, 10 ppm full scale	.0005 ppm	<2 sec with modifications (manual mode)	6	Sample gas	1 ppm NO in N_2	.5-2 ft^3/hr	1-2 hours
NO_x	Chemiluminescent	Thermo Electron Corp./14B	.05, .1, .25, .5, 1.0, 2.5, 5.0, 10 ppm full scale	.0005 ppm	<2 sec with modifications (manual mode)	6	Bendix Calibration Inst.		.5-2 ft^3/hr	1-2 hours
Ozone	Chemiluminescent	REM/612B	0-200 pphm 0-20pphm 0-2pphm	.01 pphm	< 1 sec	4	Internal Calibration	1/3 of full-scale reading	l./min	15-30 min
CO	NDIR (Fluorescence)	Andros 7000	20,50,100, 200 ppm	.1ppm	6 sec. < R.T. < 10 sec.	6	Sample Gas	10ppm CO in N_2	1-2 l./min	30 min
SO_2	Flame Photometric	Meloy SA 160	10ppm	.005ppm SO_2	15 sec lag time ≤ 30 sec response time	6	Internal Calibration or Sample Gas	.1ppm SO_2 in air		
NMHC and THC	FID	MSA 11-2	0-5ppm 0-20ppm	50ppb	20 second lag time 15 second response time	6 6	Sample Gas	10ppm C_3H_8 in N_2 10ppm CH_4 in air	2 l./min	
Temp	Thermoelectric	Cambridge Systems Mdl 137-C1-S1A-TH				6			500 ft/min or greater	5-10 min
Dew Point	Thermoelectric	Cambridge Systems Mdl 137-C1-S1A-TH				6			500 ft/min or greater	5-10 min
Altitude	Pressure	Computer Instrument Corp. Mdl 8000	0-30,000 ft	±40' to 20,000' ±0.4% above 20,000'	±20' dynamic error	6	Airport Altitude			

Table 1. LARPP/RAPS Instrumentation.

LIDAR FOR REMOTE MONITORING

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ABSTRACT

In the past the Environmental Protection Agency (EPA) has underemphasized remote sensing in its overall monitoring program. However, remote monitoring can play a valuable role in providing a new perspective in sensing the environment. As an adjunct to contact sensing, remote monitoring provides synoptic information over a wide geographical area which is important in determining pollution dispersion and predicting pollution levels and episodes. Recently, increased emphasis is being placed on remote sensing of the environment by EPA through its National Environmental Research Center located at Las Vegas, Nevada (NERC LV). This paper will discuss the research program being initiated at NERC-LV. The areas for which remote monitoring research will be conducted include air, water and possibly terrestrial pollution.

The remote monitoring technique to be discussed in this paper is LIDAR, an acronym for Light Detection And Ranging. LIDAR is similar to Radar in that it provides a range resolved measurement of scattered electro-magnetic radiation, but utilizes a pulsed laser as the source and an optical telescope as the receiver. LIDAR has applications for the remote monitoring of aerosol characteristics, sensing the height of the mixing layer and remote measurement of visibility. These applications will be discussed in detail along with a description of the mobile LIDAR unit presently under construction.

LIDAR FOR REMOTE MONITORING

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In the past the U.S. Environmental Protection Agency (EPA) has underemphasized remote sensing in its overall monitoring program. However, remote monitoring can play a valuable role in providing a new perspective in sensing the environment. As an adjunct to contact sensing, remote monitoring provides synoptic information over a wide geographical area which is important in determining pollution dispersion and predicting both pollution levels and episodes. Recently, increased emphasis is being placed on remote sensing of the environment by EPA through its National Environmental Research Center located at Las Vegas, Nevada (NERC-LV). The remote monitoring technique to be emphasized in this paper is LIDAR, an acronym for LIght Detection And Ranging. LIDAR is similar to Radar in that it provides a range-resolved measurement of scattered electro-magnetic radiation, but utilizes a pulsed laser as the source and an optical telescope as the receiver. LIDAR has applications for the remote monitoring of aerosol characteristics, sensing the height of the mixing layer and remote measurement of visibility.

Before discussing the LIDAR program, it is useful to review the role remote monitoring will play in the EPA monitoring program. Figure 1 is a block diagram of the integrated approach for monitoring systems. As is shown in the figure, an integrated monitoring system concept is developed addressing a specific monitoring need, and both remote and contact sensors contribute their unique advantages which result in an integrated system that provides the solution. The close coupling of the two techniques is also shown in the figure. Remote monitoring provides information on the optimum placement of contact sensors whereas the contact sensors provide calibration "ground truth" information for the remote sensors. Because of the wide geographical coverage inherent in remote sensing, the technique provides input to models and "quick looks" at environmental quality violations. Contact sensors also provide data for model input and can be utilized to verify violations detected remotely.

As part of an integrated system, LIDAR is being developed to assess meteorological and topographical effects on the dispersion of pollutants. Figure 2 shows an artist's concept of a LIDAR system mounted in an aircraft. The pulse of laser energy interacts with molecules and aerosols as it propagates down from the aircraft. Some of the energy is scattered back toward the telescope. Analysing the signal as a function of time provides a range-resolved indication of aerosol or particulate concentration. This range-resolved data is presented to a TV monitor resulting in a two-dimensional display of the aerosol mixing as shown in the insert of the figure. A detailed diagram of the LIDAR system is shown in Figure 3. In addition to the TV display capability, the analog data are digitized by the ADC and stored on magnetic tape for later detailed analysis. This is only one technique to provide much needed regional monitoring data. In general, the advantages of remote monitoring are:

1. Wide geographical coverage
2. Measurement above ground
3. Synoptic information
4. Input to models
5. Cost effective
6. Dispersion of pollutants
7. Placement of contact sensors
8. "Quick look" at violations

Making use of these advantages will insure that remote monitoring will have a significant role to play in the EPA's program to monitor the quality of the environment.

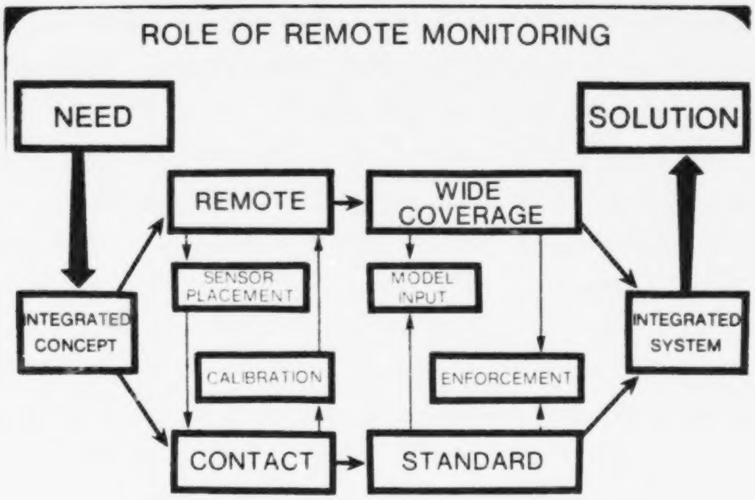


Figure 1

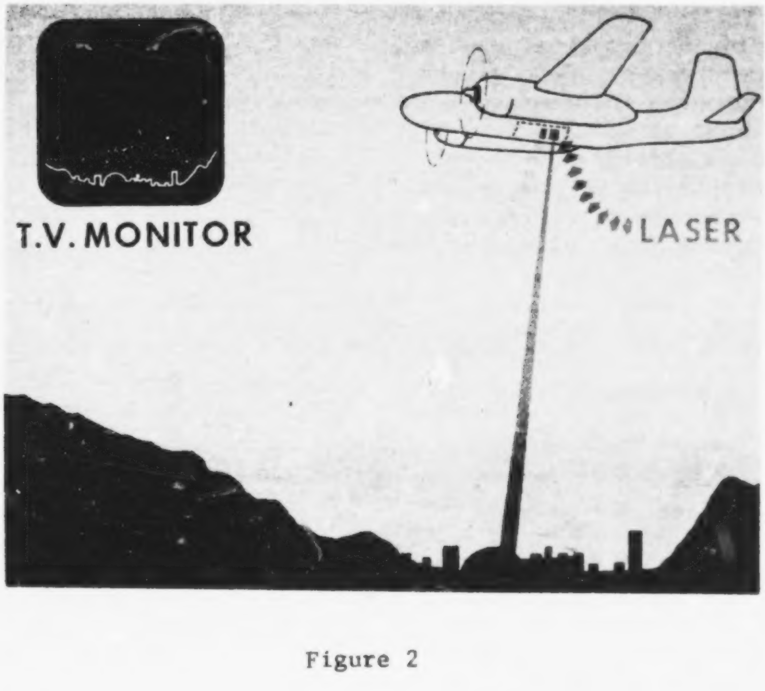
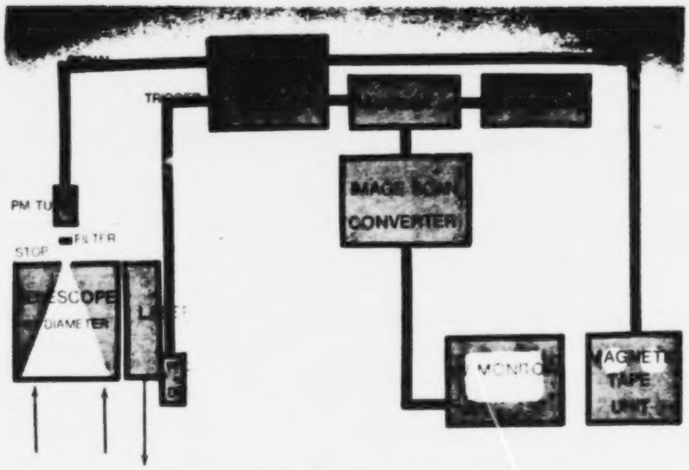


Figure 2



AIRBORNE LIDAR SYSTEM

Figure 3

EVALUATION OF THE ZEEMAN ATOMIC ABSORPTION SPECTROMETER

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ABSTRACT

The Lawrence Berkeley Laboratory (LBL), under a grant from the National Science Foundation and the U.S. Atomic Energy Commission, has designed and constructed an instrument which may be applicable for the direct analysis of mercury in the parts-per-billion range for most types of environmental samples. The U.S. Environmental Protection Agency's National Environmental Research Center in Las Vegas, Nevada, was selected to evaluate the instrument for mercury analysis in a wide variety of environmental media.

The instrument is nearly identical to the usual atomic absorption spectrometer with one major exception. Two close-lying optical lines ($\sim 1\ cm^{-1}$ apart) are used: one to monitor the atomic mercury vapor from the host material and the other to monitor the molecular vapor alone. The difference in optical absorption of these two close-lying optical lines is proportional to the atomic vapor. The lines are generated using the so-called Zeeman effect, i.e., the splitting of an optical line into two close-lying optical lines using a magnetic field. The instrument is capable of direct analysis of most types of samples in approximately 30 seconds.

Three instruments have thus far been constructed for mercury analysis. Efforts are underway at LBL to develop appropriate modifications so that the instrument can also be used for cadmium and lead analyses. Preliminary results of EPA's evaluation of one of the instruments for mercury analysis are discussed.

PRELIMINARY EVALUATION OF THE ISOTOPE ZEEMAN ATOMIC ABSORPTION SPECTROMETER

By

E. Bretthauer, W. Beckert, and S. Snyder

INTRODUCTION

The NERC-Las Vegas' Monitoring Systems Research and Development Laboratory is conducting projects concerned with the development and/or evaluation of instruments for the measurement of mercury in various media. On request of the Equipment and Techniques Division of the Office of Monitoring Systems Office of Research and Development, EPA, on April, 1973, the NERC-Las Vegas began a program in late June to evaluate a newly developed prototype instrument designed for the direct analysis of mercury in environmental samples. The instrument had been developed by Dr. T. Hadeishi and others at Lawrence Berkeley Laboratory under grants from the National Science Foundation and the U.S. Atomic Energy Commission.

This paper is a report on the progress of the evaluation to date. The remaining laboratory work is expected to be completed in early 1974, at which time a final report will be promptly initiated.

PRINCIPLE OF OPERATION

In the Isotope-shifted Zeeman Atomic Absorption Spectrometer (IZAA), the sample is thermally decomposed and oxidized in a furnace maintained at a temperature of about 900° C. Under these conditions, mercury is supposedly stable only in its elemental form. The gaseous sample is then swept into a heated absorption tube by a stream of oxygen. Here it is probed with a light beam consisting of two constituents; one has a wavelength centered on the absorption profile of natural mercury in air, while the other is slightly displaced (less than 1 cm^{-1}) from the mercury absorption line. Absorption of the centered constituent in the absorption tube is caused by mercury vapor as well as by nonmercury decomposition products - smoke, and any thermally stable molecular species present; the absorption of the displaced constituent is due only to the nonmercury products. In the vicinity of the 2537 Å mercury line, this background absorption does not change significantly over 1 cm^{-1}. Consequently, by taking the difference in the absorption of the two constituents, one determines the absorption due to mercury alone.

The heart of the technique lies in the mode in which the probe and the reference constituents are generated, and the method used to distinguish them from each other. In this instrument (see Figure 1) both constituents are supplied by a single ^{204}Hg lamp operated in a 15-kilogauss magnetic field. When such a lamp is viewed perpendicular to the applied magnetic field, the Zeeman effect splits the 2537 Å line into three components: a σ^- component shifted to longer wavelength, a σ^+ component shifted to a shorter wavelength, and an unshifted π component.

Any mercury present in the absorption tube consists of the naturally-occurring mixture of several stable isotopes. Since the absorption tube is operated at one atmosphere, the absorption lines of each isotope are pressure-broadened, and shifted slightly towards longer wavelength. In Figure 2 the resulting total absorption profile due to naturally-occurring mercury in one atmosphere of N_2 is plotted; superimposed upon this profile is the Zeeman-split emission spectrum of the ^{204}Hg lamp. Note that the π component corresponds accurately to the peak of the absorption profile of natural mercury, while the σ components are both well off on the wings of the profile. Consequently we may use the differential absorption of the π and σ components as a measure of the quantity of mercury present in the absorption tube (the π component becomes the probe beam, and the σ components taken together become the reference beam).

Another feature of the Zeeman effect provides a convenient means of separating the π and the σ components. At right angles to the magnetic field, both σ components are linearly polarized perpendicular to the field, whereas the π component is polarized parallel to the field. Consequently, either component may be viewed independent of the other with a properly aligned linear polarizer.

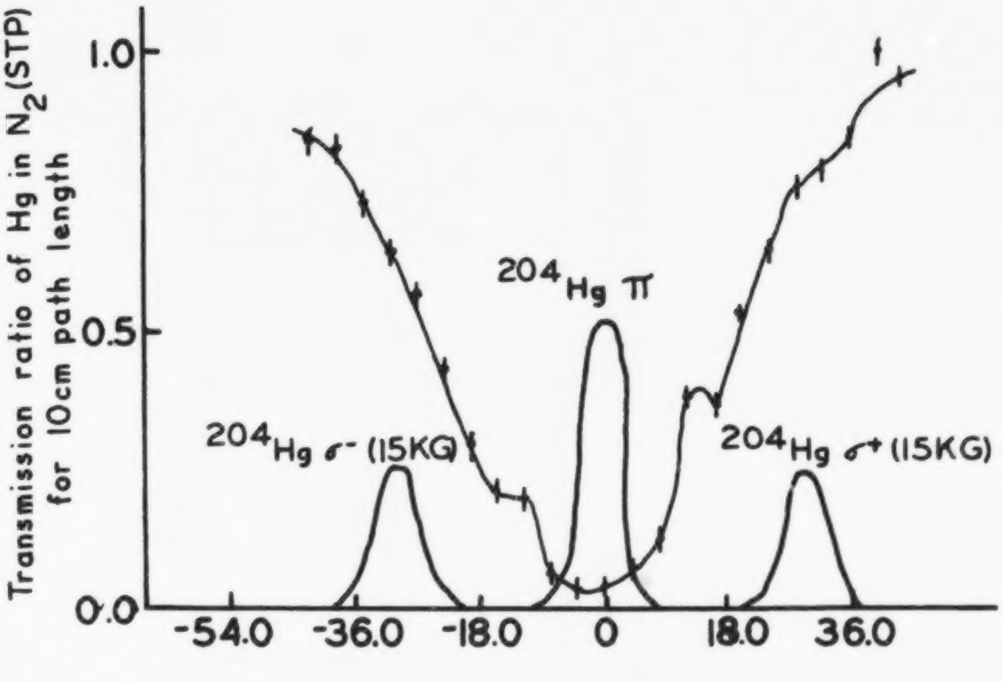

Transmission ratio of Hg in N_2(STP) for 10cm path length
1.0
0.5
0.0
-54.0
-36.0
-18.0
0
18.0
36.0
^{204}Hg π
^{204}Hg σ⁻ (15KG)
^{204}Hg σ⁺ (15KG)

Figure 1

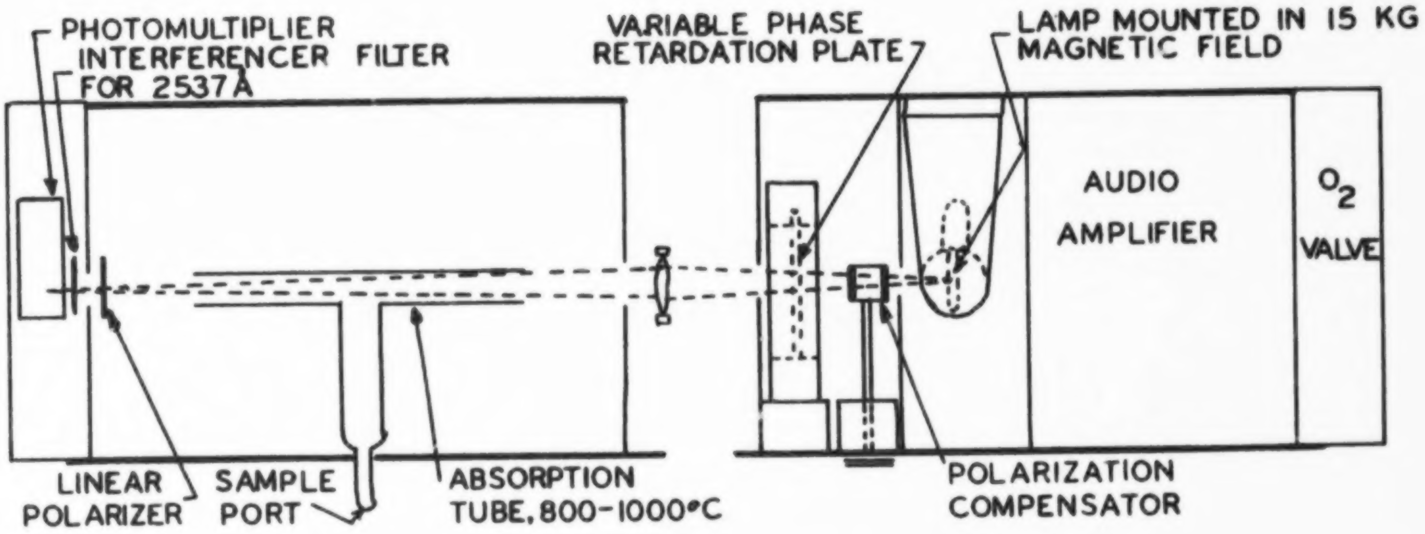

PHOTOMULTIPLIER
INTERFERENCER FILTER
FOR 2537Å
VARIABLE PHASE
RETARDATION PLATE
LAMP MOUNTED IN 15 KG
MAGNETIC FIELD
AUDIO
AMPLIFIER
O_2
VALVE
LINEAR
POLARIZER
SAMPLE
PORT
ABSORPTION
TUBE, 800-1000°C
POLARIZATION
COMPENSATOR

Figure 2

In order to optimally utilize the IZAA technique, one must employ some method of alternately allowing the probe and the reference beams to fall upon a detector after being transmitted through the absorption region. The variable phase-retardation plate accomplishes this beam switching; it exploits the optical properties of fused quartz. When fused quartz is stressed, it becomes birefringent - that is, light polarized along the stress axis propagates through the quartz at a different velocity than light polarized perpendicular to the stress axis. If a plate of fused quartz is oriented so that the stress axis forms an angle of 45° with the plane of polarization of incoming light, the birefringence of the quartz introduces a phase shift proportional to the applied stress between the two perpendicular components of the light. By appropriately choosing the stress, the quartz can be made to function as a half-wave plate.

In the present instrument, such a plate is oriented at 45° with respect to the magnetic field applied to the light source. The quartz is mounted within a C-frame pulse-transformer core on which is wound a driver coil. Since the length of the quartz plate is chosen to leave an air gap of 0.5 mm on one side of the split core, varying the current in the driver coil varies the stress on the quartz plate; we have, in effect, a magnetic clamp.

After traversing the variable phase-retardation plate described above, the light passes through the absorption tube, and falls upon a linear polarizer oriented parallel to the light-source magnetic field. When the current applied to the magnetic clamp is zero, the polarizer passes only the π, or mercury probe component of the light; when the current is adjusted so that the quartz is a half-wave plate, the quartz rotates the plane of polarization of both the π and the σ components by 90°, so now the polarizer passes only the σ, or reference components.

The light which passes the linear polarizer next encounters an interference filter which passes all components of the 2537 Å line equally well, but which discards spurious light. After leaving the filter, the light finally reaches the photomultiplier, where it generates an electrical signal proportional to its intensity. If no mercury is present in the absorption tube, the probe and reference beams are absorbed and scattered identically by the nonmercury background. Hence, as they alternately fall upon the photomultiplier, the light intensity does not change, and the photomultiplier output signal remains constant. In the presence of mercury, however, the probe component will be more strongly absorbed than the reference component, and so the photomultiplier output will vary at the audio frequency at which the switching from one beam to the other takes place. This audio component of the phototube output is extracted and amplified by a lock-in amplifier.

In practice, in order that the lock-in amplifier output be proportional to the quantity of mercury present in the absorption tube, two additional devices are necessary. The first is an amplifier with electronically-controlled gain following the photomultiplier; its gain is automatically adjusted to compensate for the attenuation of the transmitted light by the non-mercury constituents, and for variations in the intensity of the light source. The second is a quartz polarization-compensator plate - simply a piece of quartz in the light path oriented at an angle with the light beam. By varying the angle, one can compensate for accidental differences in the intensity of the probe and reference components which mimic the presence of mercury even in the absence of any sample.

EVALUATION

To evaluate the applicability of the IZAA for the determination of submicrogram quantities of mercury in various types of environmental samples, experiments were initiated to explore the following parameters:

1. Effect of sample size on signal for various types of samples.
2. Reproducibility of signal.
3. Effect of speciation on signal with emphasis on those chemical forms of mercury likely to be encountered in environmental samples.
4. Detection and sensitivity levels.
5. Interference effects (especially those likely to be encountered in environmental samples).
6. Economics of operation (man-hour/analysis, maintenance requirements, down-time, etc.).

This paper will report on experiment types 1-4 concerned with aqueous media only. Laboratory work on experiment types 1-4 concerned with other sample types as well as experiment types 5-6 will be reported subsequently.

EFFECT OF SAMPLE SIZE ON SIGNAL

Any instrument proposed for the direct analysis of mercury in environmental samples should produce a signal that is independent of sample size over some specified range. An operating range of 40 microliters was considered adequate for aqueous sample types.

Mercuric chloride standard solutions containing 0.4 to 5 ppm of mercury in 0.2N HCl were prepared and 10-, 20-, and 50-microliter aliquots analyzed with the IZAA. The results are shown in Table I. Since the standard deviations of the signal sizes overlap, the signals appear to be independent of the concentrations in aqueous systems when the sample sizes are 10-50 microliters. Similar experiments have been initiated using alfalfa, bovine tissue, blood, benzene, and ethanol samples.

REPRODUCIBILITY OF THE SIGNAL

The reproducibility of a measurement is perhaps the most important factor in selecting any analytical instrument. Various concentrations of mercuric chloride standard aqueous solutions were prepared and 10 consecutive analyses performed at each concentration. The results are shown in Table II. The relative standard deviations of the signals ranged from 2-7% over a concentration range of 0.1-5 ppm. Experiments to determine the reproducibility over lower concentration ranges for aqueous, alfalfa, bovine tissue, and blood sample types are in progress.

EFFECT OF SPECIATION ON SIGNAL

Mercury occurs in the environment in a number of chemical forms. Any instrument designed to quantitate mercury in environmental samples must provide the same signal regardless of the chemical form of the mercury. To evaluate the effect of speciation on signal, an inorganic mercury compound (mercuric chloride) and an organic mercury compound (thimerosal) were used. The primary reason for choosing thimerosal as a representative for organic mercury compounds was its relatively low volatility. Aqueous standard solutions of each of the compounds were prepared containing 8, 16, and 28 ng of mercury, respectively, per sample. Analyses of the samples using the IZAA spectrometer gave the results listed in Table III. Since the standard deviations of the signals for given quantities of mercury overlap, the values determined by the IZAA method appear to be independent of the

TABLE I

Effect of Sample Size on Signal

Mercury Standard ng/sample	Sample Size microliters	Mercury Standard ppm	Signal Average of 10 readings	Standard Deviation	Standard Error
50	10	5.0	1.870	0.062	0.021
50	50	1.0	1.944	0.051	0.017
40	20	2.0	1.668	0.058	0.016
40	50	0.8	1.520	0.032	0.010
30	20	1.5	1.431	0.087	0.025
30	50	0.6	1.269	0.020	0.006
20	10	2.0	0.879	0.039	0.012
20	20	1.0	0.940	0.064	0.020
20	50	0.4	0.942	0.045	0.014

TABLE II

Reproducibility of Signal

Mercury Standard ng/sample	Sample Size Microliters	Mercury Standard ppm	Signal Average of 10 readings	Standard Deviation
50	10	5.0	1.870	0.062
25	10	2.5	0.974	0.049
20	10	2.0	0.879	0.039
15	10	1.5	0.726	0.029
10	10	1.0	0.513	0.015
8	10	0.8	0.449	0.015
6	10	0.6	0.359	0.025
40	20	2.0	1.668	0.058
30	20	1.5	1.431	0.087
20	20	1.0	0.940	0.064
16	20	0.8	0.838	0.025
12	20	0.6	0.713	0.027
8	20	0.4	0.491	0.022
4	20	0.2	0.336	0.027
50	50	1.0	1.944	0.051
40	50	0.8	1.520	0.032
20	50	0.4	0.942	0.045
10	50	0.2	0.606	0.026
5	50	0.1	0.430	0.023

TABLE III

Effect of Speciation on Signal

Mercury Standard ng/sample	Microliters Sample Size	Chemical Form	Signal Average of 10 readings	Standard Deviation	Standard Error
8	20	Mercuric Chloride	0.513	0.024	0.011
	20	Thimerosal	0.471	0.019	0.008
16	40	Mercuric Chloride	0.766	0.022	0.010
	40	Thimerosal	0.741	0.011	0.005
28	70	Mercuric Chloride	1.089	0.020	0.009
	70	Thimerosal	1.081	0.028	0.013

chemical form of the mercury.

An experiment where the different chemical forms were combined into a single sample and analyzed indicated that the shape of the absorption curve was not always consistent. A set of experiments was therefore initiated to determine if signals from different chemical species combined in the same sample were additive.

Aqueous mercuric chloride and thimerosal standard solutions each containing 16 and 28 ng, respectively, of mercury per sample were analyzed separately. Then aliquots of the solutions containing the organic and inorganic forms, respectively, of mercury were combined and analyzed. As can be seen from the results listed in Table IV, a 20-27% signal increase over the calculated additive values was observed, when the two different chemical forms were combined and analyzed.

Preliminary experiments using a similar approach where thimerosal was replaced by phenylmercuric chloride and methylmercuric chloride, respectively, indicated a signal decrease as compared to the calculated additive values.

Experiments to determine the background of organic solvents revealed that most of the organic solvents tested, especially aromatics such as benzene, toluene, and xylene, showed a positive signal. This indicates the presence of products in the light path which show a higher absorption in the π region than in the σ region.

As these data are of extreme importance in ultimately adapting the instrument to routine environmental analysis, especially for biological samples, efforts are being made to obtain information on the origin of this non-linearity of the signal when mixtures of various chemical forms of mercury are analyzed, and on the influence of organic species on the observed analytical values.

DETERMINATION OF DETECTION LIMIT AND SENSITIVITY

The detection limit can be defined as the concentration required to give a signal-to-noise ratio of 2. Using this definition, the minimum detection level for mercury in an aqueous sample was found to be 0.4 ng. The sensitivity of mercury using the IZAA (1% absorption) was found to be 4 ng.

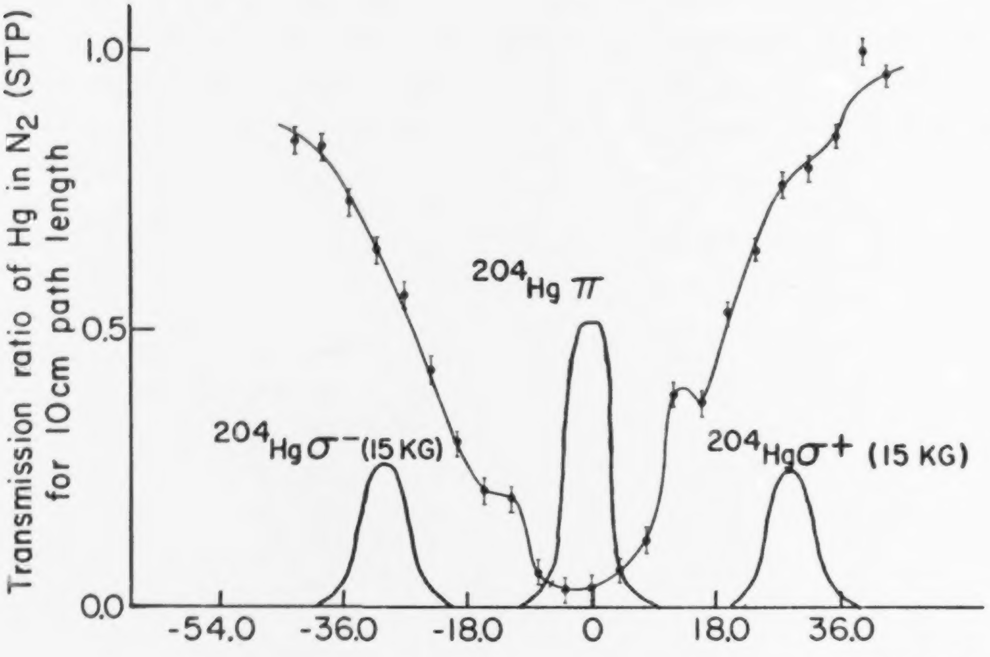
TABLE IV

Effect of Combining Different Chemical Forms on Signal

#	Chemical Form	Mercury Standard ng/sample	Signal Average 10 readings	Calculated Signal	% Difference
1	Mercuric Chloride	16	0.766		
2	Thimerosal	16	0.741		
3	Mercuric Chloride	28	1.089		
4	Thimerosal	28	1.081		
5	Mercuric Chloride Thimerosal	8 8	0.957	0.754	+27%
6	Mercuric Chloride Thimerosal	8 20	1.341	1.085	+24%
7	Mercuric Chloride Thimerosal	20 8	1.306	1.085	+20%

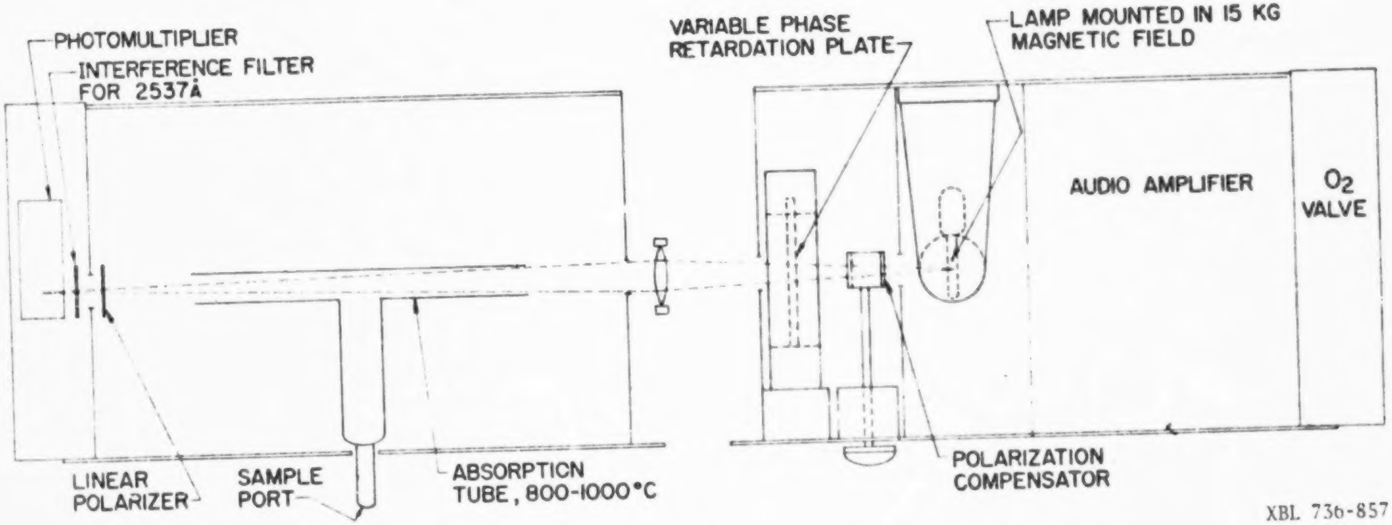
CONCLUSION

These preliminary results indicate acceptable reproducibility in the concentration range 0.1 - 5.0 ppm and a reasonable independence of signal from concentration (0.4 - 5.0 ppm) and sample size (10-50 μl), for aqueous solutions. The signal is reasonably independent of the chemical form of mercury; however, combinations of different chemical forms of mercury in the same aqueous sample produced signals which were non-additive.



XBL 731-105A

Fig. 3


PHOTOMULTIPLIER
INTERFERENCE FILTER FOR 2537Å
LINEAR POLARIZER
SAMPLE PORT
ABSORPTICN TUBE, 800-1000°C
VARIABLE PHASE RETARDATION PLATE
LAMP MOUNTED IN 15 KG MAGNETIC FIELD
AUDIO AMPLIFIER
O_2 VALVE
POLARIZATION COMPENSATOR

XBL 736-857

Fig. 2

SESSION II

NASA-LANGLEY SENSOR PROGRAMS

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MULTIWAVELENGTH LIDAR FOR REMOTE SENSING OF CHLOROPHYLL a IN PHYTOPLANKTON

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and Clarence A. Brown, Jr.

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Presented at the Second Environmental Quality Sensor Conference

Las Vegas, Nevada
October 10-12, 1973

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BIOGRAPHICAL SKETCH

Dr. Mumola received his B.S.E.E. from Polytechnic Institute of Brooklyn in 1965, his M.S.E.E. from New York University in 1966, and his Ph. D. in E.E. from the University of Texas in 1969. He served in the U.S. Army, Corps of Engineers, from June 1969 until May 1971, during which time he was assigned to NASA's Electronic Laboratory in Boston to conduct research on lasers, dye lasers, and associated electronic equipment.

From May 1971 until September 1973, Dr. Mumola was employed at NASA's Langley Research Center to continue his work on dye lasers. During this period, Dr. Mumola developed a four-wavelength dye laser pumped by a single common flashlamp. Dr. Mumola's 7 years' experience in lasers have been in both atmospheric and water, and he has become a leader in the field of dye lasers.

Presently, Dr. Mumola is employed by the Perkin-Elmer Corporation of Norwalk, Connecticut.

Mr. Jarrett received his B.S. in Mechanical Engineering (Aero option) from North Carolina State University in 1962 and his M.S. in Engineering Mechanics from Virginia Polytechnic Institute and State University in 1968. Mr. Jarrett has been employed at NASA's Langley Research Center since 1962. During his employment, Mr. Jarrett has conducted research in plasma physics and infrared laser systems. Mr. Jarrett is currently engaged in measuring water quality utilizing a laser system.

Mr. Brown is a Senior Aerospace Engineer with 24 years' experience in aerospace research. Mr. Brown received his B.S.A.E. from Auburn University in 1948 and his B.S.M.E. from Auburn University in 1949. Since 1949, Mr. Brown has been employed at NASA's Langley Research Center and has conducted research in stability and control of aircraft and missiles, reentry physics, meteor simulation, and project engineering and management. In the past 2 years, Mr. Brown has applied his research skills and background knowledge to applications of remote sensing of water using LIDAR systems.

MULTIWAVELENGTH LIDAR FOR REMOTE SENSING OF CHLOROPHYLL a IN PHYTOPLANKTON

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ABSTRACT

A theoretical and experimental analysis of laser induced fluorescence for remote detection of chlorophyll a in living algae and phytoplankton is presented. The fluorescent properties of various species of algae representative of the different color groups are described. Laboratory measurements of fluorescent scattering cross sections is discussed and quantitative data presented. A "scattering matrix" model is developed to demonstrate the essential requirement of multiwavelength laser excitation in order to make accurate quantitative measurements of chlorophyll a concentration when more than one color group of algae is present in the water (the typical case). A practical airborne laser fluorosensor design is considered and analysis of field data discussed. Successful operation of the Langley ALOPE (Airborne LIDAR Oceanographic Probing Experiment) system is described and field measurements presented. Accurate knowledge of α, the optical attenuation coefficient of the water, is shown to be essential for quantitative analysis of chlorophyll a concentration. The feasibility of remotely measuring α by laser radar is discussed.

INTRODUCTION

The application of laser radar (LIDAR) technology to the remote detection of fluorescent materials, notably oil and chlorophyll a, in natural waters has been actively pursued by several groups in the United States and Canada. Thus a common appreciation for the value of remote sensing to the oceanographic community and to those responsible for water quality management is assumed. NASA Langley Research Center has initiated a program to develop an airborne fluorosensor with a multiwavelength laser for detection of chlorophyll a in living algae where more than one color group may be present.

LABORATORY SPECTRAL STUDIES

Since chlorophyll a is insoluble in water, this molecule is found in a host material, namely, algae and phytoplankton. The optical properties of the host material alter the fluorescence excitation and emission

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spectra of the chlorophyll a molecule. Therefore, knowledge of the optical properties of the algae as it is found in nature, rather than in acetone extract solution, is required for remote detection application.

During the past year LRC personnel have measured the fluorescence excitation and emission spectra of over 45 different species of algae representative of the four major color groups (blue-green, green, golden-brown, and red). Using Rhodamine B as the fluorescence standard, the effective fluorescence cross section has been computed as a function of excitation wavelength for each species. The apparatus used in these studies is shown in Figure 1. A fluorescence spectrophotometer, Hitachi Perkin-Elmer model MPF-2A, was modified to improve its red sensitivity. The spectra were recorded on both a strip chart and magnetic tape, the latter being used for input to computer programs for cross-section computation. Excitation spectra were measured by setting the emission monochromator to 685 nm, the chlorophyll a fluorescence peak, and scanning the excitation wavelength from 360 nm upward through the visible spectrum. Both monochromators were set to 5 nm slit widths to obtain usable signal levels without destroying the spectral resolution. Emission spectra were then recorded by setting the excitation monochromator to the optimum excitation wavelength (determined above) and scanning the emission monochromator from that wavelength upward to 800 nm. Similar spectra were measured using a 10^{-7} molar solution of Rhodamane B in ethanol. Cross sections were then computed using these spectra and accounting for instrumental effects such as monochromator transmittance and lamp spectral intensity. Figure 2 shows typical results for algae of each color group. Note in the emission spectra that each color group emits strongly at 685 nm due to the presence of chlorophyll a, though other fluorescent components may also be present. The excitation spectra differ from one color group to another, each having a unique region for optimum excitation. Spectra within any given color group are, however, remarkably similar as shown in Figure 3 for golden-brown algae. Therefore, one can characterize the fluorescent excitation properties of any algae by the color group to which it belongs. Note that these cross sections were computed for single molecules of chlorophyll a and a spectral resolution of 5 nm. This will be important in the analysis which follows.

It should be noted that no single excitation wavelength can be chosen to uniformly stimulate chlorophyll a fluorescence in all algae. Spectral overlap also precludes selective excitation of any one color group of algae. One method of measuring the concentration of chlorophyll a can be shown in the LIDAR equation given below.

$$P_{rec} = \begin{cases} \dfrac{\xi A}{2R^2}\,\dfrac{\Delta\lambda_D}{\Delta\lambda_f}\,{\dfrac{\theta_r}{\theta_l}}^{2}\,\dfrac{\sigma_f(\lambda_l)\,n\,P_o(\lambda_l)}{(\alpha_f+\alpha_l)} & \text{For single fluorescent scatterer} \\ \text{or} & \\ \dfrac{\xi A}{2R^2}\,\dfrac{\Delta\lambda_D}{\Delta\lambda_f}\,{\dfrac{\theta_r}{\theta_l}}^{2}\,\displaystyle\sum_{j=1}^{4}\dfrac{\sigma_{fj}(\lambda_l)\,n_j\,P_o(\lambda_l)}{\alpha_f+\alpha_l} & \text{For four different fluorescent scatterers} \end{cases}$$

where

ξ = optical efficiency of receiver

A = effective area of telescope primary mirror (m^2)

$\Delta\lambda_D$ = detector bandwidth (nm)

$\Delta\lambda_f$ = fluorescence bandwidth (20 nm)

θ_r = receiver field of view (rad)

θ_l = laser beam divergence (rad)

n = density of chlorophyll a (molecules/m^3)

σ_f = effective fluorescence cross section (m^2)

P_o = laser output power (W)

λ_l = laser wavelength (nm)

α = attenuation coefficient of water (m^{-1})

P_{rec} = fluorescent power received (W)

and subscripts f and l refer to fluorescence and laser wavelengths, respectively. If all algae were equally excited at a given wavelength, then the upper form of the equation (for single σ_f) would be appropriate. As previously shown, algae of each color group possess different cross sections and therefore the bottom form of the LIDAR equation is required. Since the algae color groups have different fluorescence excitation spectra, the use of four wavelengths yields four equations. These equations can thus be solved simultaneously to yield the unknown chlorophyll a concentration contained in each color algae. In matrix form this can be expressed as

$$\begin{bmatrix} P_{rec}(\lambda_1) \\ \cdot \\ \cdot \\ \cdot \\ P_{rec}(\lambda_4) \end{bmatrix} = C_1 \begin{bmatrix} \frac{P_o(\lambda_1)}{\alpha_f+\alpha_1} & 0 & \cdots & 0 \\ 0 & \frac{P_o(\lambda_2)}{\alpha_f+\alpha_2} & \cdots & 0 \\ 0 & 0 & \cdots & \frac{P_o(\lambda_4)}{\alpha_f+\alpha_4} \end{bmatrix} \begin{bmatrix} \sigma_{f1}(\lambda_1) & \cdots & \sigma_{f4}(\lambda_1) \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \sigma_{f1}(\lambda_4) & \cdots & \sigma_{f4}(\lambda_4) \end{bmatrix} \begin{bmatrix} n_1 \\ \cdot \\ \cdot \\ \cdot \\ n_4 \end{bmatrix}$$

or

$$\begin{bmatrix} P_{rec}(\lambda_1) \\ \cdot \\ \cdot \\ \cdot \\ P_{rec}(\lambda_4) \end{bmatrix} = C_1 \, \pi \chi \begin{bmatrix} n_1 \\ \cdot \\ \cdot \\ \cdot \\ n_4 \end{bmatrix}$$

Therefore

$$\begin{bmatrix} n_1 \\ \cdot \\ \cdot \\ \cdot \\ n_4 \end{bmatrix} = C_1^{-1} \, \chi^{-1} \, \pi^{-1} \left\{ \begin{matrix} P_{rec}(\lambda_1) \\ \cdot \\ \cdot \\ \cdot \\ P_{rec}(\lambda_4) \end{matrix} \right\}$$

The elements contained in the χ matrix are obtained from the cross-section measurements previously described. The laser power at each wavelength can be measured and controlled. Accurate knowledge of α at all the appropriate wavelengths is essential for quantitative determination of chlorophyll a concentration. Since $\alpha_f > \alpha_l$ for all laser wavelengths under consideration (450 nm - 650 nm), and the optical window of water decreases with increased wavelength, at least α_f must be known to yield quantitative measurements. In open waters, data are available indicating that α does not vary rapidly in time or space. In estuarine and coastal waters changes are more rapid and frequent measurements of α must be obtained.

Assuming α is known or measurable, the above matrix technique can be used to determine the concentration of chlorophyll a in the algae present in a body of water and the distribution of chlorophyll a in the different color groups.

MULTIWAVELENGTH LIDAR INSTRUMENT

Figure 4 shows a schematic of the airborne LIDAR system which has been designed and fabricated at Langley Research Center to demonstrate the multiwavelength concept of chlorophyll a detection. The laser used in the system is a unique four-color dye laser pumped by a single linear xenon flashlamp. Figure 5 shows a cross-sectional view of the laser head. The head consists of four elliptical cylinders spaced 90° apart with a common focal axis. The linear flashlamp is placed along this axis and its radiant emission is equally divided and focused into the dye cuvettes located on the surrounding focal axes. Fluorescent dyes form the active medium for the four separate dye lasers. A rotating intracavity shutter permits only one color at a time to be transmitted downward to the water.

The resulting fluorescence from the chlorophyll a is collected by a 25.4-cm-diameter Dall-Kirkham type telescope. The signal is then passed through a narrow bandpass filter centered at 685 nm and on to the photomultiplier (PMT) tube. The PMT signal is digitized by a waveform digitizer and stored on magnetic tape for later analysis. The dyes and the water for the flashlamp are kept at a uniformly cool temperature by the refrigerator. The high voltage supply, charging network, coaxial capacitor, trigger generator, and a spark gap along with a central control system complete the package. Figure 6 shows the completed system prior to installation in a helicopter for flight evaluation.

Field tests have been performed to demonstrate the capabilities of this new technique. Experiments have been conducted from a fixed height platform (George P. Coleman bridge, Yorktown, Virginia) 30 meters over the York River. This site was selected because it was convenient to both Langley Research Center and the Virginia Institute of Marine Science (VIMS). Ground truth data (chlorophyll a concentration, salinity, and algae species identification) were supplied by VIMS using standard water sampling techniques. The attenuation coefficient (at 632.8 nm) and temperature of the water were measured on site by Langley personnel.

Measurements were made every half-hour on the evening of July 9, 1973, and data are shown in Figure 7 along with ground truth data supplied by VIMS. Chlorophyll a concentrations shown represent the total chlorophyll contribution of all color groups. A bioassay performed by VIMS indicated a dominance of golden-brown (dinoflagellates) and green algae. The ratio of golden-brown to green algae varied over the course of these measurements and was in general agreement with observations obtained with the LIDAR system.

On July 25, 1973, the LIDAR system was successfully flight-tested over the James River between Hampton Roads and the Chickahominy River. Flight altitude was 100 meters and the speed was 120 km/hr. The flight path is shown in Figure 8 along with the chlorophyll a concentration measured over the 138-kilometer round-trip flight. During each flight leg the laser was fired at a rate of 0.5 pps. The data plotted in Figure 8 represent average chlorophyll a concentration over each leg. For example, leg No. 16 data represent an average of 63 laser firings of each color or 252 shots total. There is sufficient data, however, from each four-color cycle to determine chlorophyll a content without averaging. In fact, the data collected over the entire flight (approximately 75 minutes long) represent nearly 500 separate chlorophyll a measurements.

SUMMARY AND CONCLUSIONS

A multiwavelength laser fluorosensor has been developed to remotely measure chlorophyll a concentration in living algae in natural waters. Preliminary field operation of the instrument and technique has been demonstrated from both fixed height and airborne platforms. The maximum operational altitude of the present system is approximately 300 meters (estimate based on data acquired at 100 meters). Laser energies varied with color from 0.6 mJ (454.4 nm) to 7.15 mJ (598.7 nm). These values are well within the eye safe limits at the operational altitude of 100 meters. Greater energies could be employed to accommodate higher altitude operation. System stability appears to be excellent as evidenced by the fact that laser alinement has remained constant for over 6 months.

The major disadvantage of all optical remote sensors of water constituents is their dependence on foreknowledge of α (or its components "a" and "s" due to absorption and scattering, respectively) to make quantitative measurements. This is true for the multiwavelength LIDAR technique as well. Data can only be analyzed quantitatively when α is known. Studies are now underway to determine the feasibility of remote α measurements by LIDAR techniques. It may be possible, with slight instrument modifications, to monitor α simultaneously with the chlorophyll a concentration.

ACKNOWLEDGMENTS

The authors are grateful for the cooperation of Drs. Franklin Ott and Robert Jordan of the Virginia Institute of Marine Science for obtaining laboratory algae sample and ground truth data and to Messrs. L. G. Burney, C. S. Gilliland, and B. T. McAlexander of NASA Langley Research Center for their assistance in the design, fabrication, and testing of the LIDAR flight instrument.

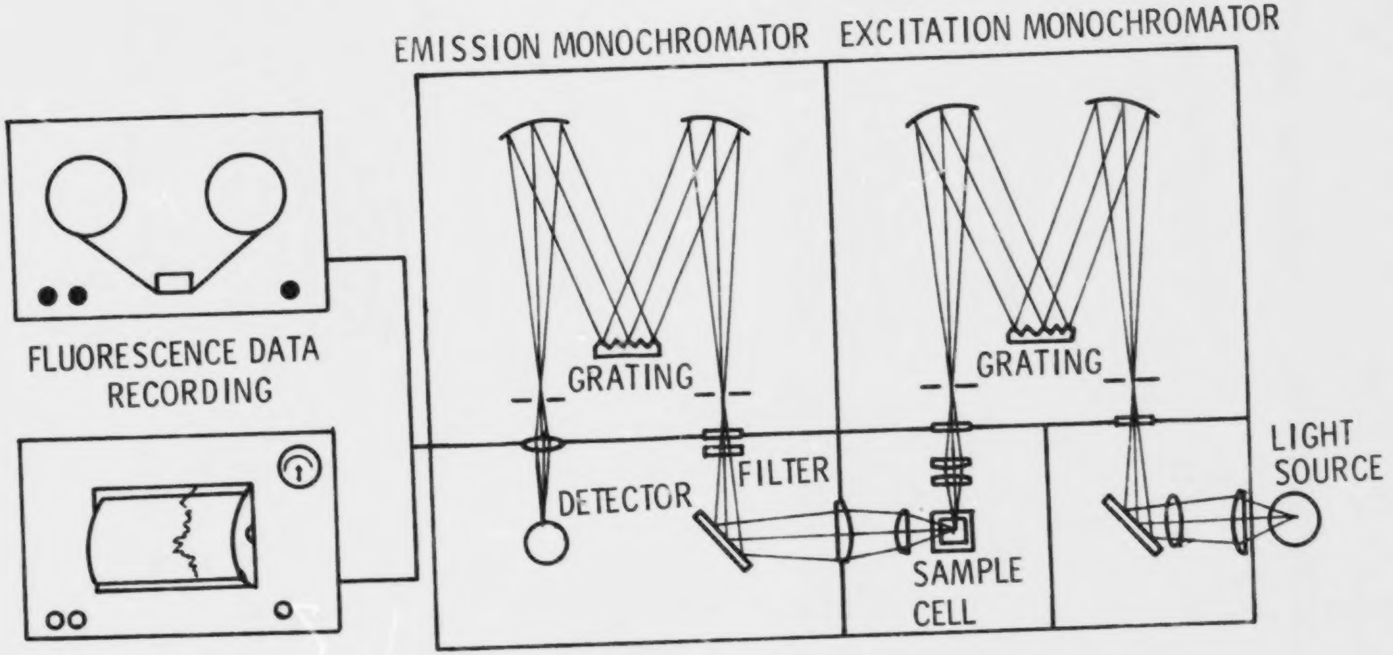

Figure 1.- Laboratory apparatus used in fluorescence excitation and emission studies.

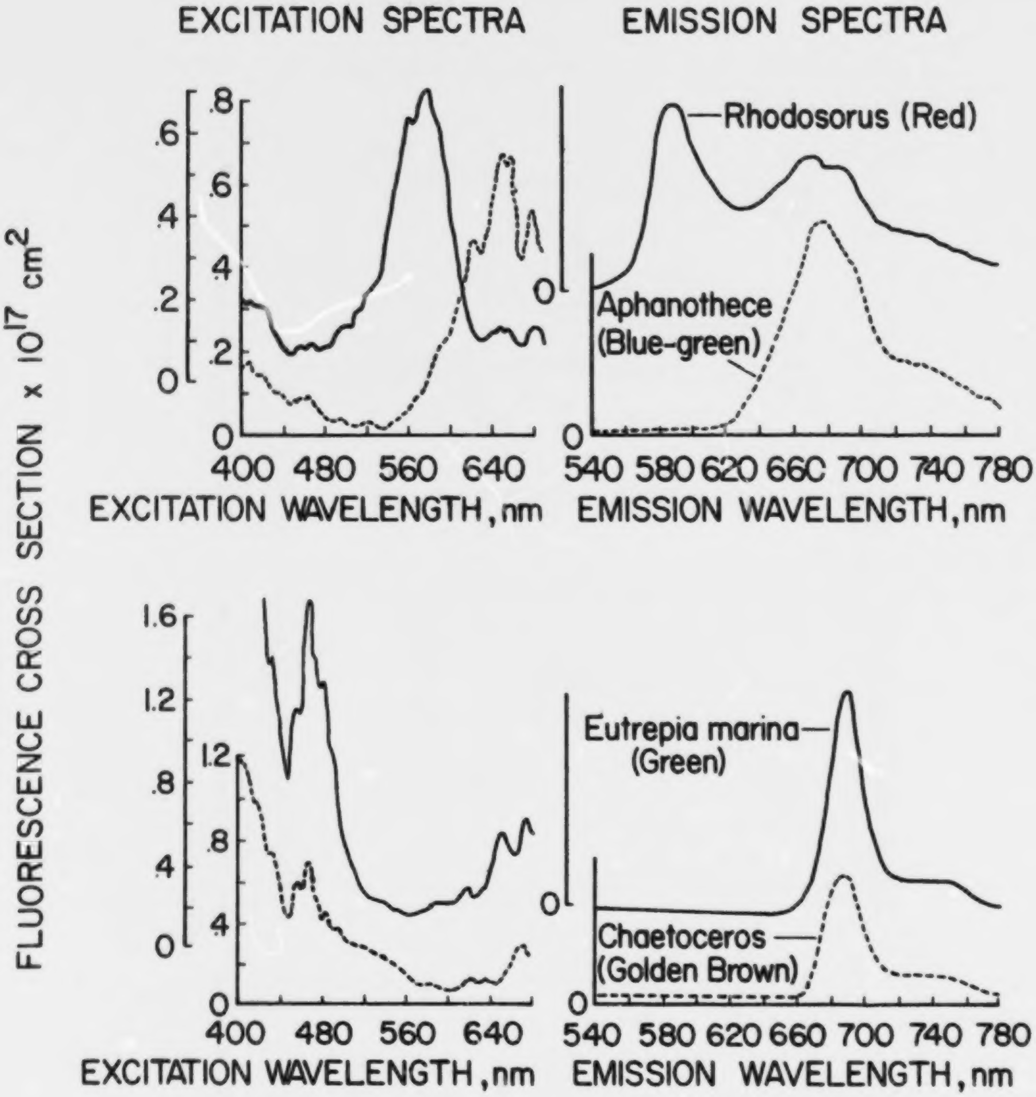

Figure 2.- Typical fluorescence cross-sections and emission spectra of red, blue-green, green, and golden brown algae samples.

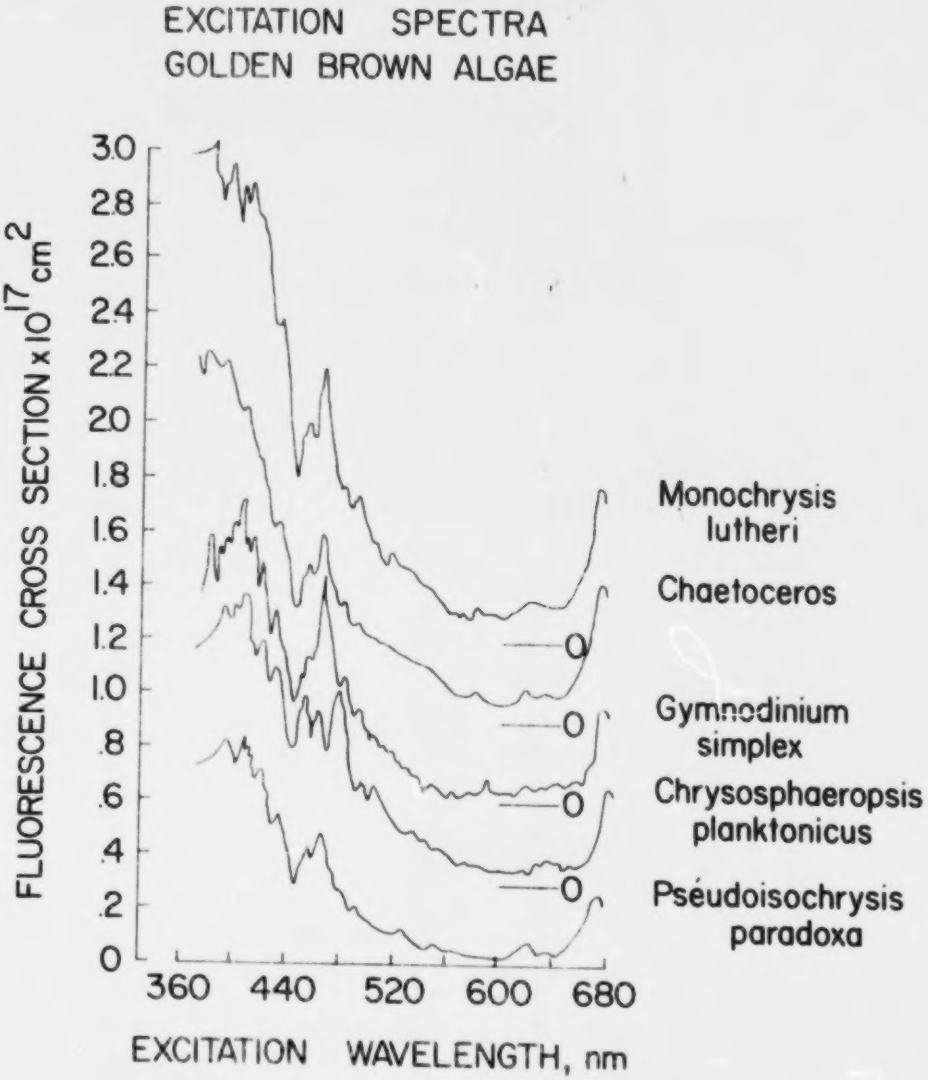

Figure 3.- Effective fluorescence cross-sections of chlorophyll a in golden brown algae. Data shown are normalized to single molecule values with a 5 nm resolution.

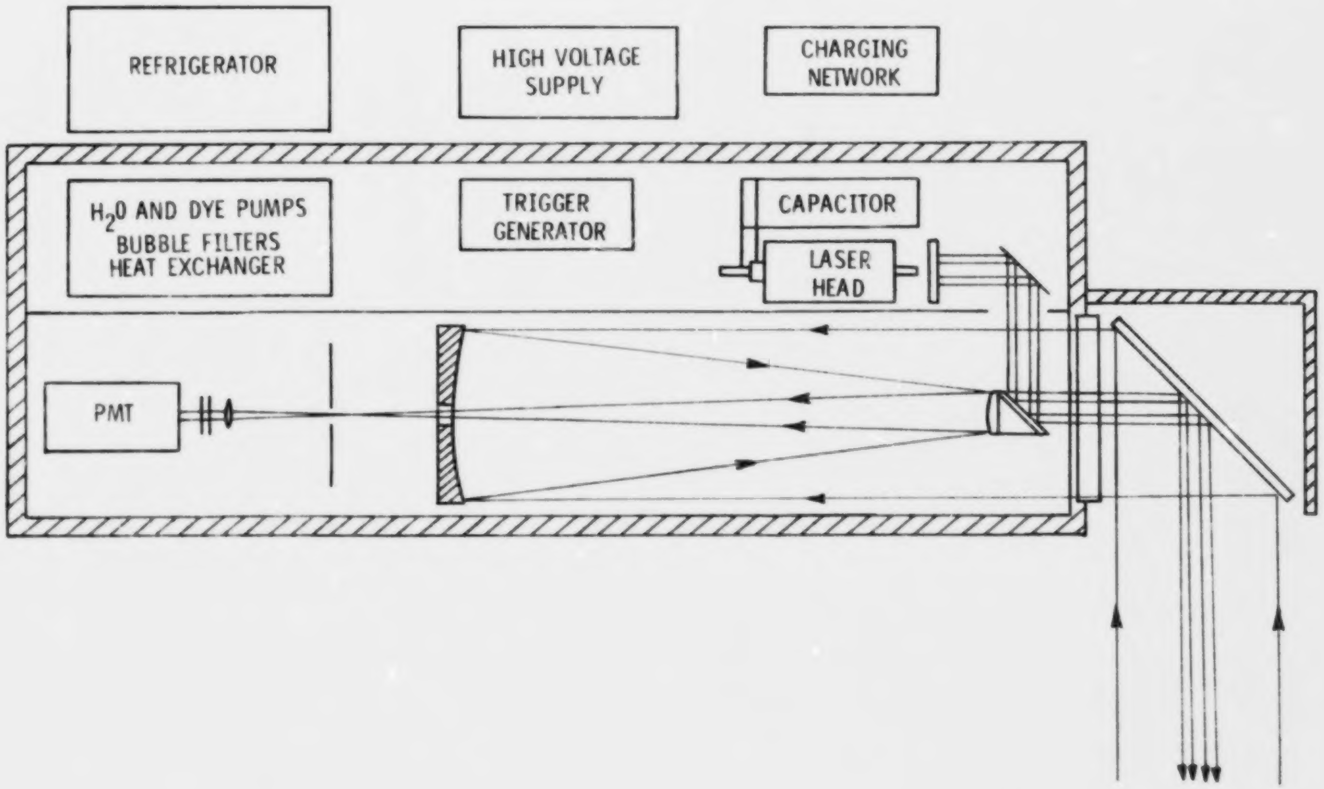

Figure 4.- Schematic of the airborne multi-wavelength LIDAR system.

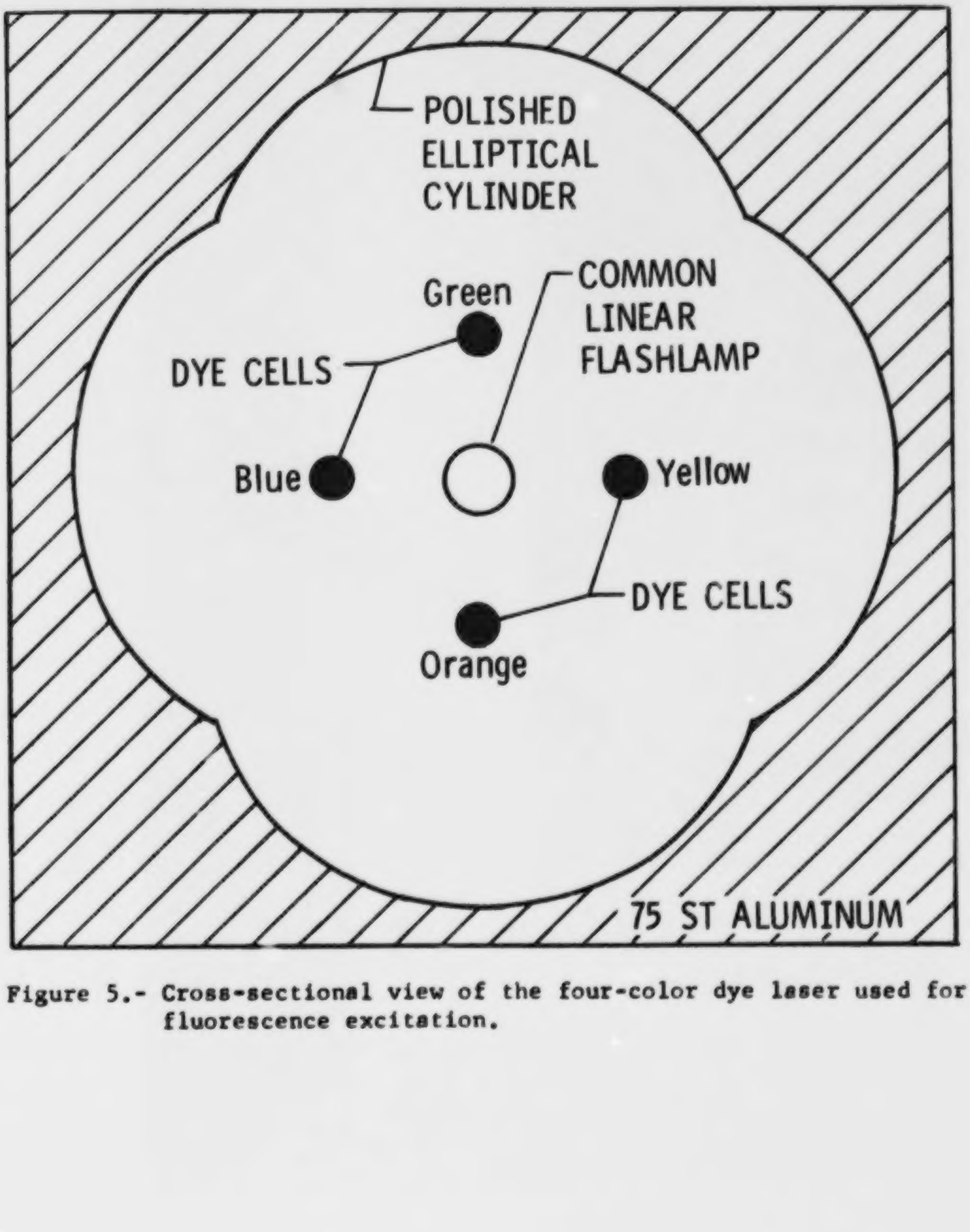

Figure 5.- Cross-sectional view of the four-color dye laser used for fluorescence excitation.

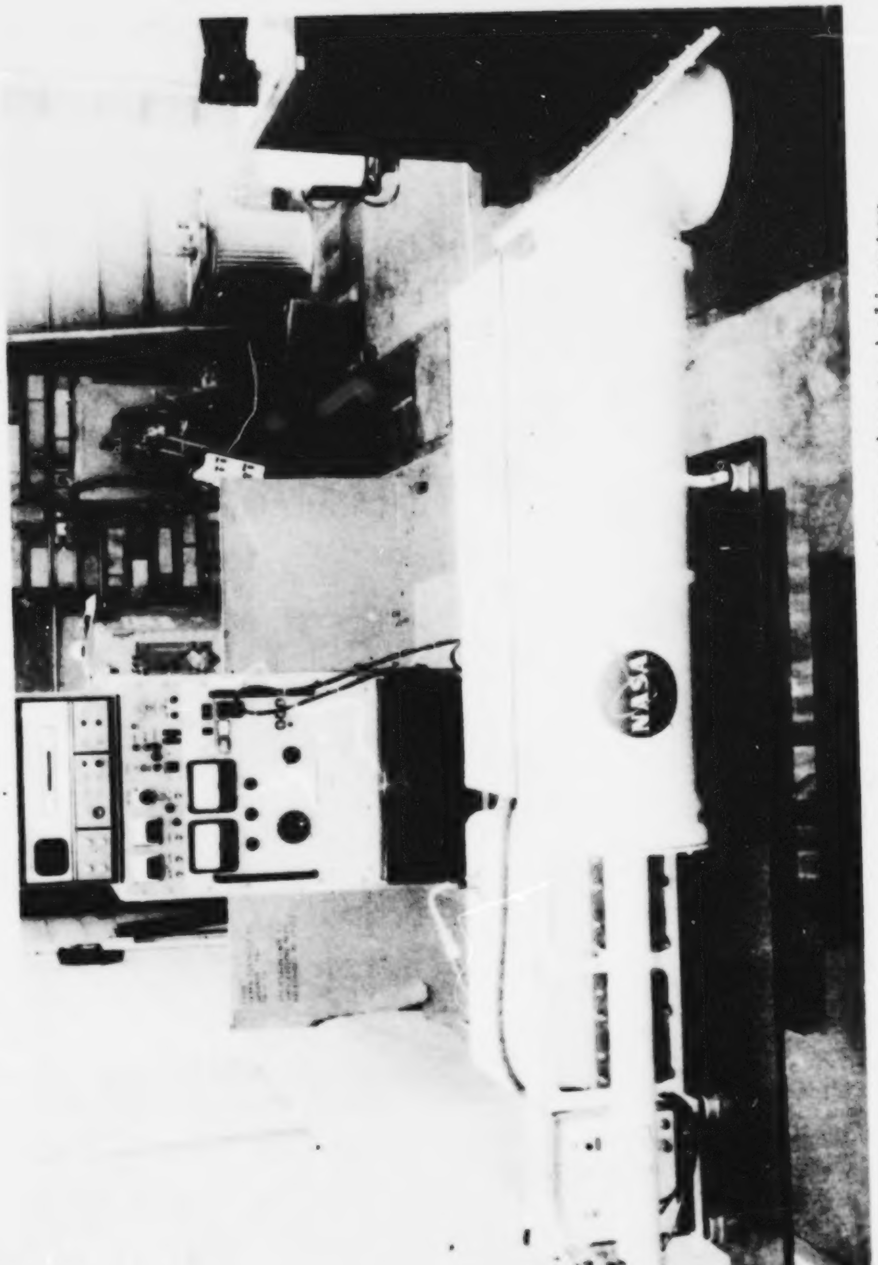

Figure 6.- Photograph of complete LIDAR package prior to helicopter installation.

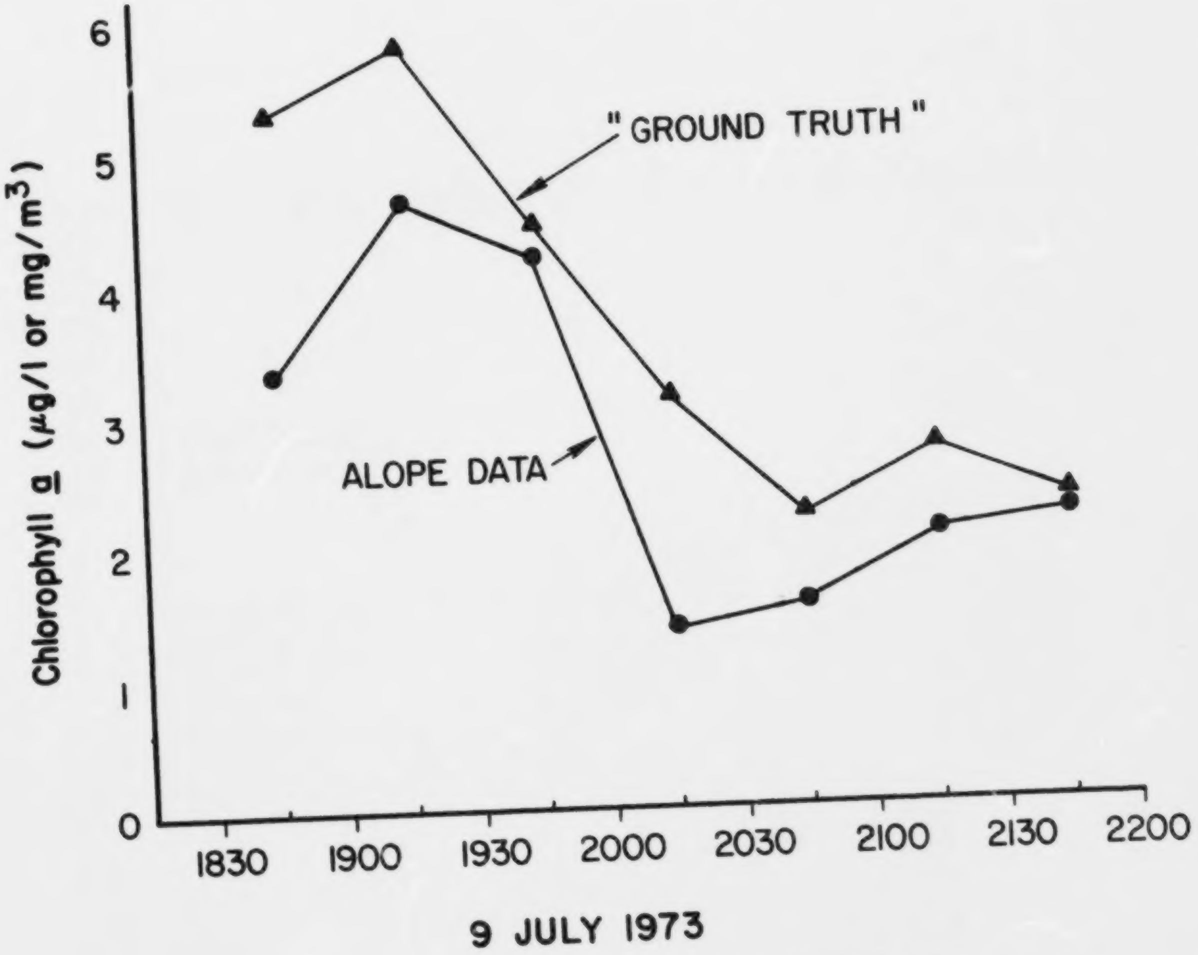

Figure 7.- Field data acquired from a fixed height platform over the York River near Yorktown, Virginia.

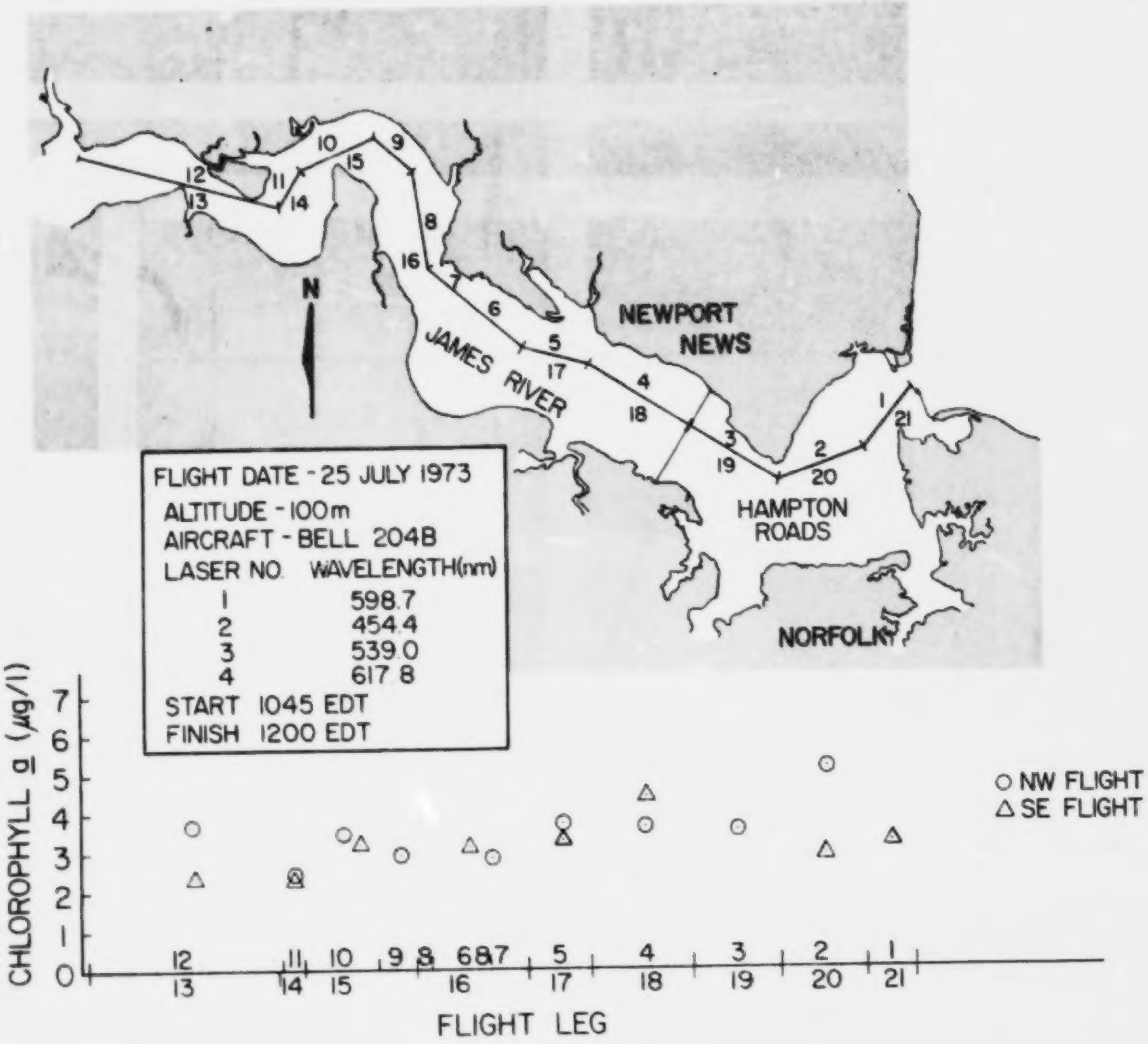

Figure 8.- Flight data acquired over the lower James River.

REMOTE DETECTION OF WATER POLLUTION
WITH MOCS: AN IMAGING MULTISPECTRAL SCANNER

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Presented at the Second Conference on
Environmental Quality Sensors

Las Vegas, Nevada
October 10-11, 1973

REMOTE DETECTION OF WATER POLLUTION WITH MOCS: AN IMAGING MULTISPECTRAL SCANNER

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BIOGRAPHICAL SKETCH

Mr. Grew received his B.S. degree in Physics from Northeastern University in 1961, and has done graduate work at Virginia Polytechnic Institute. From 1961 to the present time he has worked at the Langley Research Center in basic and applied research. This research includes such topics as: design and development of flight instrumentation, solid state detection devices, radiation sensors, radioactive sensing techniques, meteoroid research, and remote sensing. He worked on a meteoroid experiment on Explorer XXIII and was project engineer and coinvestigator for the meteoroid experiments on Lunar Orbiter flights I through V. Mr. Grew is currently investigating the application of remote sensing of ocean color to environmental pollution problems.

ABSTRACT

Aircraft flights to collect spectral data using MOCS (Multichannel Ocean Color Sensor) are being conducted in an effort to establish algorithms which correlate with and distinguish between water pollutants, including algae and sediment. Data collected over Clear Lake, California, New York Bight, and off Cape Hatteras demonstrate the value of MOCS as a remote sensing tool in studying the hydrosphere. A spectral signature extracted from the Clear Lake data has identified the type of algae in the lake. The New York Bight and Cape Hatteras data reveal a peculiar signature associated with the transition from blue water to a turbid water mass. This transitional signature may be useful as a calibration point for remotely determining the concentrations of the suspended materials in the surrounding waters.

INTRODUCTION

Remote sensing of ocean color is currently under investigation at the Langley Research Center (LaRC) with the prime objective of developing the capability of producing, by means of spacecraft and aircraft instrumentation, periodic maps which display the distributions of pollutants, including algae and sediment, in our oceans and inland waters. This investigation is being conducted with MOCS (Multichannel Ocean Color Sensor), a unique multispectral scanner designed and developed under NASA contract by TRW, Inc, as part of the AAFE (Advanced Applications Flight Experiments) Program. Under this

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contract MOCS was successfully flight tested on the NASA Convair 990 over various water bodies. A flight was also conducted in the New York Bight area in a program sponsored by the National Oceanic and Atmospheric Administration (NOAA). Examples of data from both missions are presented in this paper. Flights supported by ground truth are planned for EPA over the Potomac River. Several flights have been scheduled, but weather conditions were unfavorable.

With MOCS it appears feasible that a user agency can periodically overfly a given water body and generate, from the spectral data collected, maps which identify the suspended materials in the water and which contour their distributions. The feasibility of remotely detecting water pollutants with MOCS has been demonstrated (Refs. 1,2). The degree to which pollutants can be distinguished and quantified by this technique requires further investigation.

Additional flight data supported by ground truth data are needed not so much to test instrument capability, but rather to establish optimum data processing techniques. Before contour maps of water bodies can be automatically outputted, spectral signatures must be established that correlate with the various suspended materials. Computer techniques exist which automatically correlate multispectral data, separate data points into classes, and generate maps which distinguish land and water features by color coding. These classification programs can tell the user nothing about what each color coded feature might be, but only that each color shades areas that emit similar spectral signatures. For land maps, the user must identify known features (e.g., wheat fields) that correlate with each color. His task is diminished by several factors: (1) Land features are often separated by sharp boundaries, (2) land features are often unchanging (i.e., deserts) or change gradually (i.e., vegetation), and (3) classified features can be verified by ground truth days after the overflight.

The situation is quite different for water masses. Water bounderies generally are not sharp and changes can occur rapidly. The establishment of an algorithm that correlates with a particular feature is hampered by the variation in the spectral signature of the water mass. While the spectral signature emitted from various parts of a given corn field can be fairly consistent, the signature from a water mass can vary continuously between its extremities. Consider, for example, the spectral signature of sediment. Because of the absorptive and reflective properties of water and sediment, the upwelling spectral signature may vary with composition, size distribution, and vertical distribution of the sediment. In some cases, however, algorithms can be established readily when only one pollutant is present. For example, an algae bloom can be easily identified because it is highly concentrated at the water surface. Incident light on the bloom cannot penetrate very far below the surface. The upwelling light presents to the remote spectroradiometer a unique spectral signature of the algae. An example of a bloom signature will be given later in this paper.

The situation becomes more complex when mixtures of pollutants occur. Each pollutant may have different absorption and scattering properties and with multiple, interactive scattering the resultant upwelling signature is not necessarily the sum of the individual signatures. Furthermore, the upwelling signature may vary continuously when a gradual transitional region between two water masses is traversed. Advanced computer programs will be needed to automatically handle data of this type, particularly in coastal regions. (The processing of open ocean data may not be as complex since mixtures are rarer and the suspended matter is primarily phytoplankton.) These programs must be capable of classifying features, analyzing signature variations between the classified features, and displaying this information to the user in a meaningful form.

Examples of MOCS data for two different types of water masses are presented in this paper: (1) An algae bloom which has a well-defined signature that can be readily processed on a computer and (2) a plume of suspended matter which is complex in composition and in spectral signature. The new information extracted from both cases demonstrates the value of a multispectral scanner, such as MOCS, as a tool for studying processes that occur in the hydrosphere.

MOCS INSTRUMENT DESCRIPTION

The MOCS is a visible imaging spectroradiometer which performs multispectral scanning electronically. It has no moving parts. MOCS was specifically designed for measurements of small differences in ocean color from space. It measures the intensity in 20 spectral bands at each of 150 spatial sites of the ocean across the field-of-view. It is unique in that it uses only one detector and, as a result, it is compact and very light, weighing only 23 pounds.

Figure 1 is a schematic of the optical arrangement of MOCS and a listing of its specifications. In operation, light from the water is focused by the objective lens on the entrance slit. The instrument is designed to form a high-quality optical image of the ocean surface on the slit, so that light from one edge of the field-of-view is imaged at one end of the slit, light from the center of the field is imaged at the center of the slit, etc. The light is then collimated, dispersed by a blazed transmission diffraction grating, and reimaged on the face of the image dissector. The resulting image consists of a large number of adjacent spectra, each one composed of radiation coming from a different site across the instantaneous field-of-view. The spectra are scanned in sequence in a raster pattern on the photosensitive surface of the tube. The resulting video signal is a measure of the spectral intensities of the light coming from each of 150 spatial sites. The scan rate is such that the whole raster (one frame) is read out in the time (286 msec) it takes the spacecraft or aircraft to move forward over the ocean one resolution element. The scan is then repeated at a rate of about 3.5 frames/sec to give contiguous coverage of the ocean. The field-of-view of the MOCS for two different altitudes is given in Table I.

The present MOCS system has an alternate mode of operation made possible by changing the image dissector. In this mode the spectral resolution (5 nm) is increased by a factor of 3 at the expense of a factor of 3 reduction in spatial resolution.

The output of MOCS is fed to an A/D converter and stored on magnetic tape. The bit rate from the converter is 140 Kbits/sec. A detailed description of MOCS and its associated electronics can be found in Reference 1. Figure 2 is a photograph of MOCS.

SPECTRAL SIGNATURE OF ALGAE

An example of a well-defined spectral signature of a water mass consisting essentially of one pollutant was obtained from MOCS data of Clear Lake, California, on the NASA Convair 990 mission. The lake was overflown on June 28, 1972, at an altitude of 37,400 feet. The map in Figure 3 shows the flight path across the lake and the total field-of-view (2 by 18 miles) of the MOCS along the path.

False color maps of Clear Lake, shown in Figure 4, were generated from the MOCS data. The algorithms to use are:

$$\text{Green Band:} \qquad Y_j = \frac{I_{11,j} - I_{9,j}}{I_{10,j}} \qquad (1)$$

and

$$\text{Red Band:} \qquad Y_j = \frac{I_{20,j} - I_{19,j}}{I_{10,j}} \qquad (2)$$

where $I_{i,j}$ is the magnitude of band i of the spectrum from spatial element j of the MOCS data. The bands 9, 10, 11, 19, 20 correspond, respectively, to center wavelengths of 528, 543, 558, 678, and 693 nm. Selection of the two algorithms is based on data (discussed in Ref. 2) which support the assumptions that the green band map shows the distribution of all particulate matter near the lake's surface, whereas the red band map shows only the distribution of algae. Therefore, the strong feature in the lower part of the lake, which appears in both maps, is assumed to be an algae bloom.

Using a computer program developed at LaRC, regression analysis was performed on MOCS data points within this bloom in an attempt to extract a spectral signature of the algae. A linear regression equation was assumed of the form

$$Y_j = A_i I_{i,j} + B_i \tag{3}$$

where Y_j is the value of a given algorithm for spectrum j, and A_i and B_i are constants for each band. Several algorithms were tested, including those of Equations (1) and (2). The results were essentially the same (Fig. 5). Figure 5 is a plot of A_i, the slope of the regression equation for each of the 20 spectral bands. In this example, the algorithm

$$Y_j = I_{20,j} - I_{19,j} \tag{4}$$

was used. In essence, this plot shows the spectral signature of the algae bloom. The ordinate is the relative change of the signal in band i with a relative increase in the algae concentration (assuming the algorithm in Equation (4) correlates directly with concentration). With an increase in concentration, the signal in the blue bands decrease due to absorption by the plant pigments. The chlorophyll a absorption peaks in bands 4 and 19 are clearly evident. In the green and red bands the signals increase as expected due to scattering. The known scattering peaks in the green (band 12) and the red (band 20) standout. The crossover point, known as the hinge point, between absorption in the blue and scattering in the green occurs at band 10. At the hinge point no signal change occurs with a change in algae concentration. Duntley (Ref. 3) reported the hinge point for marine algae to be at 523 nm. It appears that for this fresh water specie the hinge point occurs at 543 nm. The algorithm in Equation (4) was presented in order to show where this hinge point occurs. If Equation (2) or (3) were used, the normalization factor I_{10} would normalize the data to band 10 and thereby obscure the fact that the hinge point occurs at that band.

Figure (6) shows absorption spectra of several different phytoplankton species that were measured in the laboratory by the author on a Cary 14 spectrophotometer. The spectral signature in Figure 5 looks very similar to the inverted spectrum of Anacystis marinus, a blue-green algae. The predominant organism in the lake one day after the flight test was a blue-green algae (Aphanizomenon). These data demonstrate, perhaps for the first time, that a remote sensor can be used to identify the type of algae in the water in addition to mapping its relative distribution.

NEW YORK BIGHT DATA

A water mass more complex than the algae bloom just presented is exhibited in the New York Bight data. The assumed complexity is based upon the observed variations in the spectral data along a path across the water mass. The data reveals a peculiar transitional signature - a sequential variation in the spectrum - that might be significant in establishing remotely reference points of known concentrations within water masses.

MOCS data collected in the New York Bight on April 7, 1973, was part of the Marine Ecosystems Analysis (MESA) Program being conducted by NOAA. The New York Bight mission was organized and directed by the National Environmental Satellite Service (NESS), a branch of NOAA. Data were collected with various instrumentation aboard both aircraft and boats. The general objectives of this mission were to expand our knowledge of the coastal marine processes and at the same time demonstrate the value of remote sensing in achieving that objective.

NASA-LaRC participated in the mission by flying MOCS in an NASA Wallops C-54 aircraft. Ten passes, each approximately 30 n. mi. long, were made over the Bight at an altitude of 17,500 feet. The ground resolution (Table I) of MOCS was 35 feet by 70 feet with a total swath width of 5,250 feet.

Figure 7 is an ERTS I image (600 - 700 nm band) of the New York Bight obtained on the morning of the mission. The morning sky was cloudless and clear; the sea was very smooth. The afternoon was marred by a continuous buildup of haze. An unusually large plume of suspended matter was clearly evident in the Bight fed by the Hudson River. Fairly sharp rectangular boundaries of this plume can be seen in Figure 7. Beyond the plume is an acid waste dump. MOCS data taken over this dump has been used to construct a false color map (Fig. 8). This map contours the region in which the upwelling signal is greater than 50% of the maximum upwelling signal in the 573-nm band. At the outer boundary of this map the strength of the acid is 50% of that at the center of the dump. To demonstrate the sensitivity of the instrument, the map is color coded in 5% intervals down to the 60% level; the last two intervals are uncolored. The sharpness of the contour lines illustrates the excellent resolution of MOCS.

Many interesting signature variations are exhibited in the MOCS data of the Bight. Correlation studies will be performed on these data when the ground truth data become available. As an example of these variations, the data along one flight track (designated 45-1) will be presented. This flight path is shown in Figure 9.

Plots of data along the center of the track for three spectral bands are shown in Figure 10. The ordinate has been adjusted such that the upwelling signal from blue water is equal to zero relative signal. Each data point in Figure 10 is an average of four spatial elements which reduce the resolution to 70 feet by 140 feet. A change of one frame count corresponds to an advancement of 140 feet along the flight line. For purposes of discussion, the ocean along the track has been divided into regions, designated R1, R2, etc., in Figure 10.

The plots demonstrate the complex variation in the upwelling signal as the aircraft flew over blue water, crossed the plume boundary, passed over the plume, and approached land. Region 1 consisted of relatively clear blue water, although coincident signal variations in the three bands in the latter half of the region indicate small features. In Region 2, the signals for the three bands increase as the plume boundary is approached. Within the plume, Region 3, the relative magnitudes of the three bands diverge. The blue band (468 nm) decreases, the orange band (603 nm) increases, and the green band (543 nm) remains relatively constant. In Region 4 the blue and green bands fall and rise together while the orange band remains relatively constant. Notice that the blue band has dropped to zero relative signal. In Region 5 all bands rise. The divergence that occurred in Region 3 appears to be reversing in Region 6. However, as land is approached, bottom reflection appears to influence the directional variance of the signals in both Regions 6 and 7.

It is instructive to examine the relative signal variations between bands by plotting the data as shown in Figures 11 and 12. Figure 11 is a plot of every third point in Figure 10 for the blue and orange bands. The cluster of points which fall within each region is indicated in the figure. The sequential variation of the data is clearer in Figure 12, where lines are drawn between the averages of sets of 20 data points along the track.

At least two models are suggested by these signal variations. In the first model the variations are due to the size and depth distributions of sediment along the track. Backscattered light from clear water is the result of selective scattering, known as Rayleigh scattering, by water molecules and small particles (Ref. 4). Rayleigh scattering predominates when the size of the scatterers are much smaller than the wavelengths of the scattered light. The amount of scattering is inversely proportional to the fourth power of the wavelength. In addition, water molecules selectively absorb light much more strongly in the red end of the spectrum than in the blue, greatly reducing the amount of red light available for backscattering. However, as the size of the suspended particles increases to the order of one micrometer, Mie scattering (Ref. 4) becomes significant. Mie scattering is predominantly in the forward direction and is nonselective with wavelength. As a result, scattering decreases in the blue region of the spectrum and increases in the red region. However, since the particles in the water are not of one size, the analytical analysis becomes more complex.

With this model the data in Figure 10 could be explained as follows. In Region 2, the particles are small and distributed somewhat evenly below the surface. As the boundary is approached, the number of particles increase. Within the plume, the particles are larger and more numerous resulting in a considerable reduction in the photic zone. The transition from a low concentration of small particles to a high concentration of larger particles results in a decline in the signal in the blue bands and a rise in the red bands.

A second model is suggested by the fact that algae absorbs light in the blue bands and scatters light in the red bands. Therefore, the variation in signals in Regions 2 and 3 could also be influenced by the transition from a region of primarily sediment to a region of algae mixed with sediment. The ground truth may resolve these possibilities.

A very similar occurrence of this signal variation is seen in MOCS data collected along the 36° parallel off Cape Hatteras. This flight was part of the NASA Convair 990 mission. Data were collected at 37,300 feet starting about 40 n. mi. offshore and ending at the shoreline. The similarity between Figures 13 and 14 for the Cape Hatteras data and Figures 11 and 12 for the New York Bight data is striking. Perhaps this phenomenon is a fundamental characteristic of certain types of plumes and can be useful in establishing reference points of known concentrations. In other words, the transitional signature, the triangle in Figure 14, could be uniquely associated with certain distributions of the suspended matter. If known concentrations can be associated with this signature, then the distribution of the matter in the surrounding region can be determined. Reference points of this nature would be invaluable in the processing of remote sensing data.

CONCLUDING REMARKS

The examples of data presented in this paper demonstrate the value of multispectral scanners, such as MOCS, as a remote sensing tool for analysis of processes that occur within the hydrosphere. From the Clear Lake data, a spectral signature was extracted which identified a feature, observed in a false color map of the lake, as a blue-green algae bloom. The false color map shows the relative concentrations of this bloom. Generation of maps of this type which display absolute values of concentration using remote sensing data appears to be quite feasible.

The sensitivity of MOCS is demonstrated by the well-defined contour lines (color coded in 5% intervals) on the false color map of the acid waste dump in the New York Bight.

The New York Bight data also revealed a signature associated with the transition between two water masses. Examination of the Cape Hatteras data showed the same transitional signature. The value of this signature has not been fully determined, but it has the potential of establishing reference points of known concentrations and could be invaluable in the processing of remote sensing data of the hydrosphere. These examples demonstrate the complexity of the signatures associated with suspended matter. Signatures may vary gradually and continuously, not only between water masses, but within them. To facilitate user application of data of this type, computer programs are needed that can properly assess the signature variations and display on maps in a meaningful form the variations in the water associated with these signatures.

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3. Duntley, Seibert Q.: "Detection of Ocean Chlorophyll From Earth Orbit." Fourth Annual Earth Resources Program Review, Vol. IV, Presented at the Manned Spacecraft Center, Houston, Texas, January 17-21, 1972.

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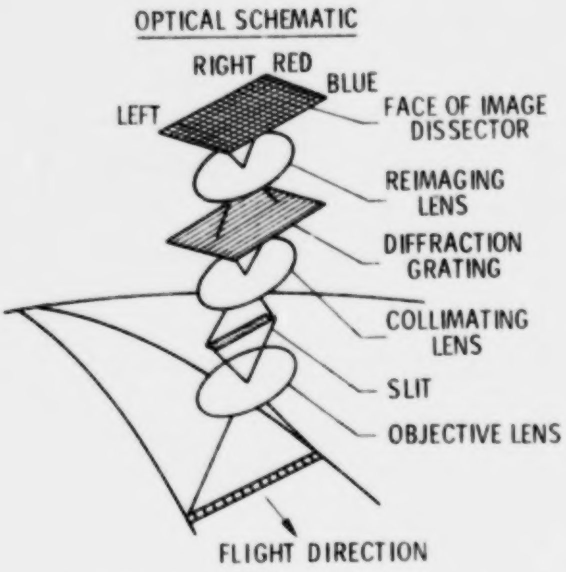
TABLE I. FIELD-OF-VIEW OF MOCS

	Aircraft	Spacecraft
Altitude	17,500 feet	500 n. mi.
Field-of-view	17.1°	17.1°
Swath width	5,250 feet	150 n. mi.
Ground resolution	35 by 70 feet	1 by 2 n. mi.



SPECIFICATIONS

400-700 nm SPECTRAL RANGE
15 nm SPECTRAL RESOLUTION
20 SPECTRAL BANDS
150 SPECTRA/ SWATH WIDTH
17.1° FIELD OF VIEW
22.5 pounds
7.5 watts
.35 cubic feet

Figure 1. Optical schematic and specifications of MOCS.

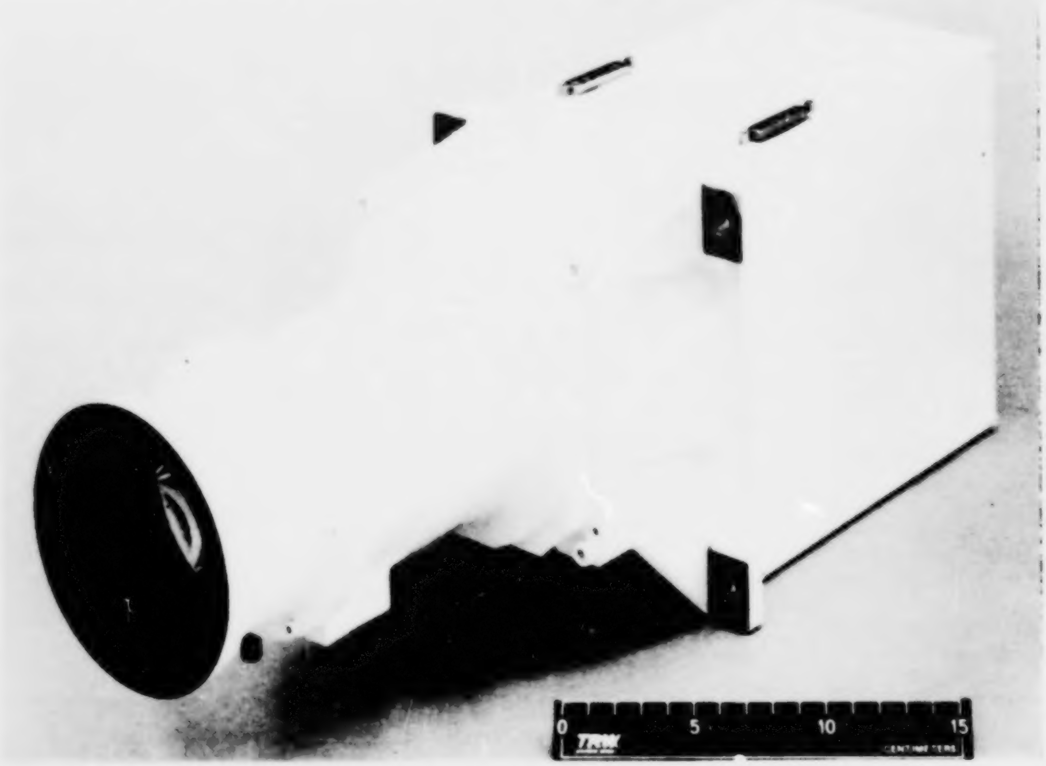


Figure 2. Photograph of MOCS.

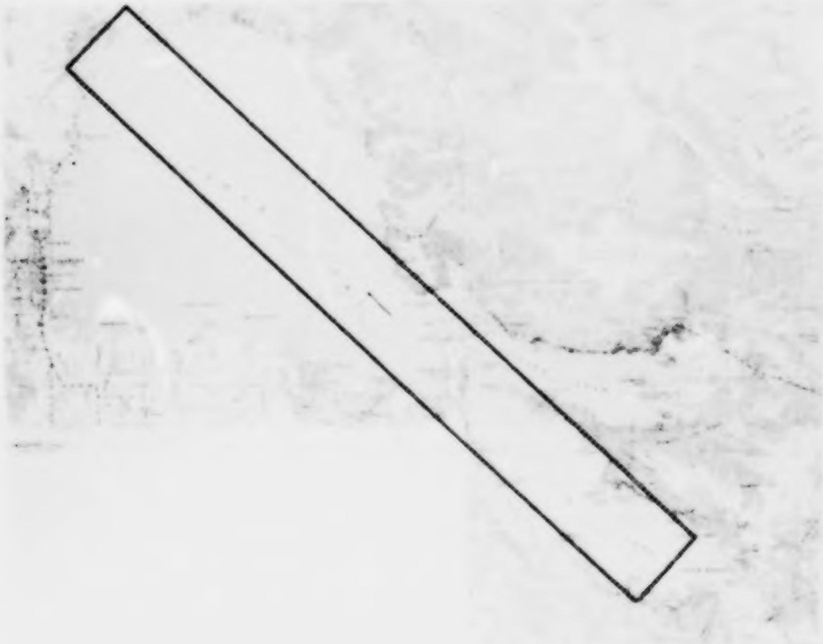
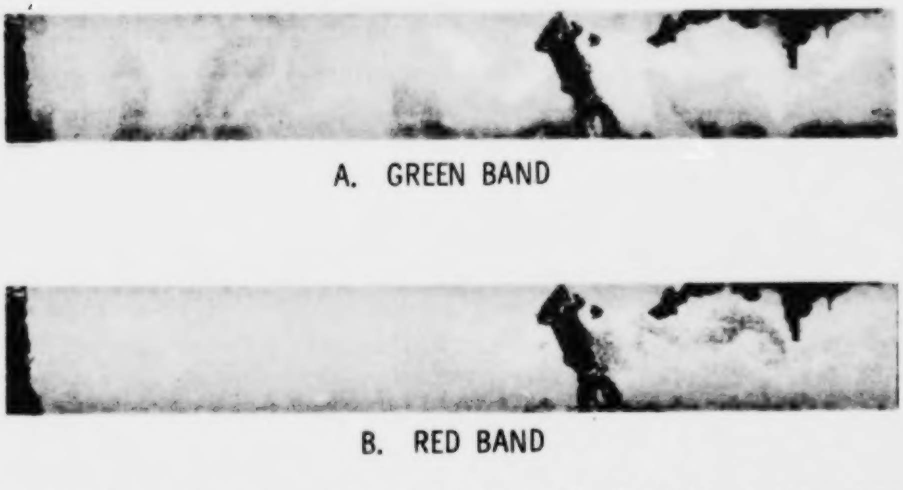


Figure 3. Flight path of NASA Convair 990 and field-of-view of MOCS (2 by 18 miles) over Clear Lake at 37,400 feet.



A. GREEN BAND

B. RED BAND

Figure 4. False color maps (originals in color) of Clear Lake generated from green band and red band algorithms.

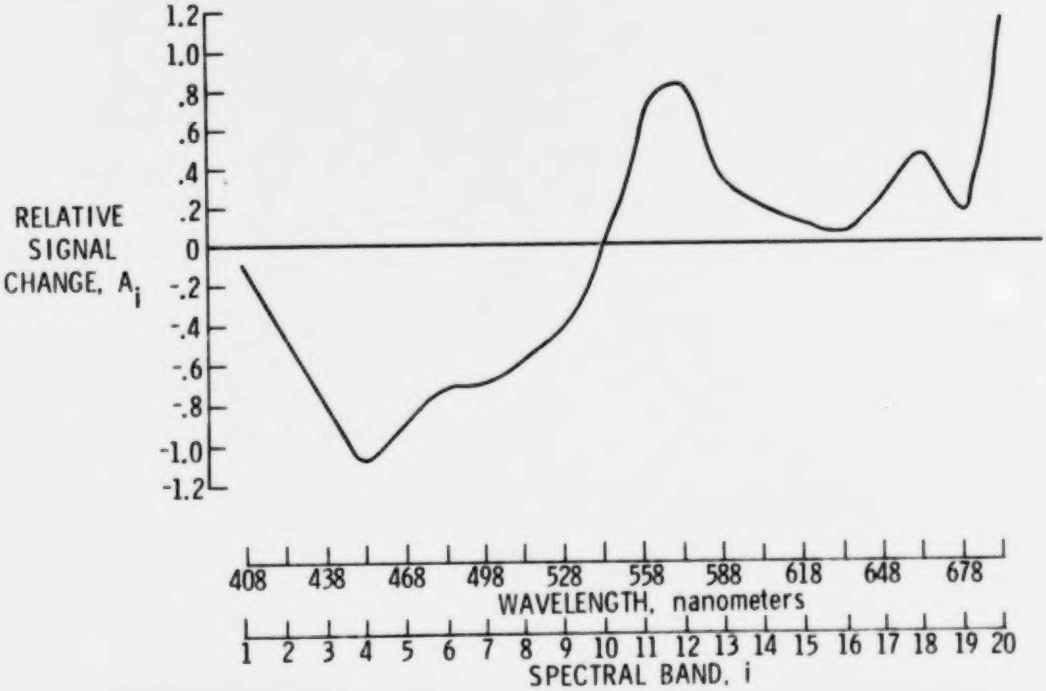


Figure 5. Spectral signature of an algae bloom in Clear Lake.

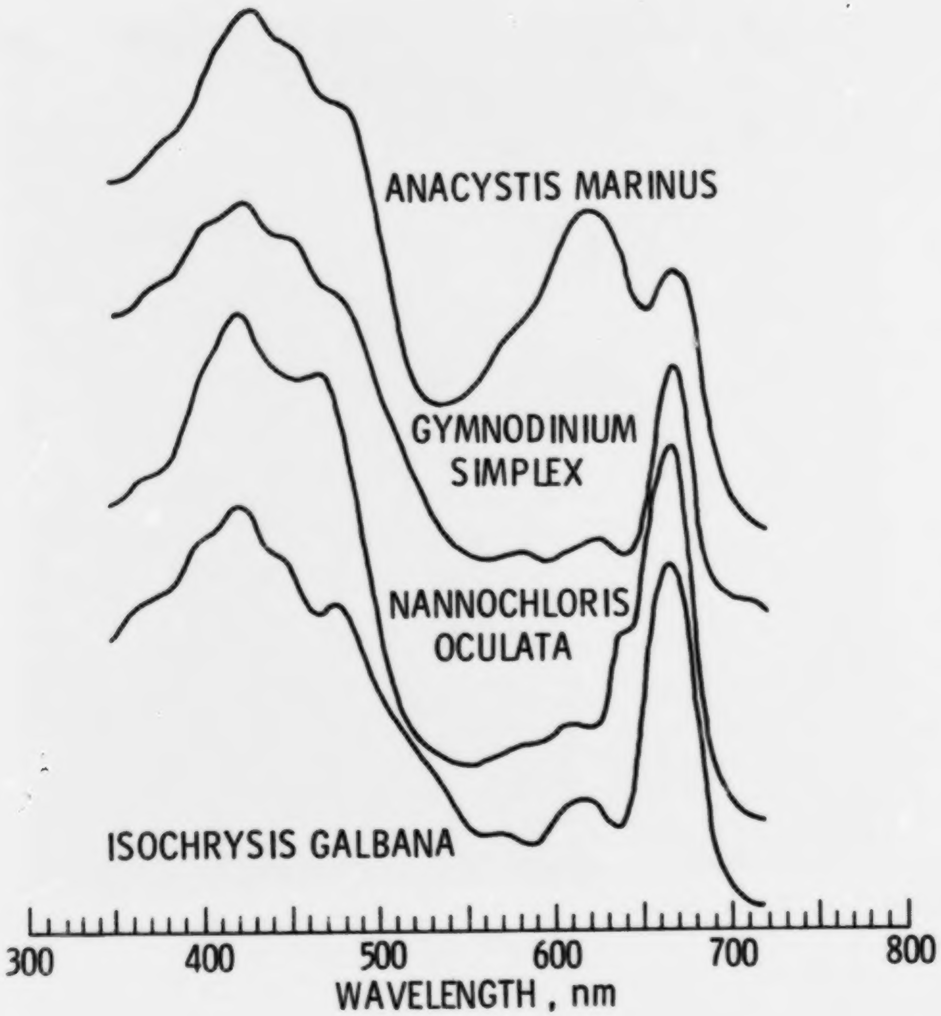


Figure 6. Absorption spectra of sample phytoplankton species.

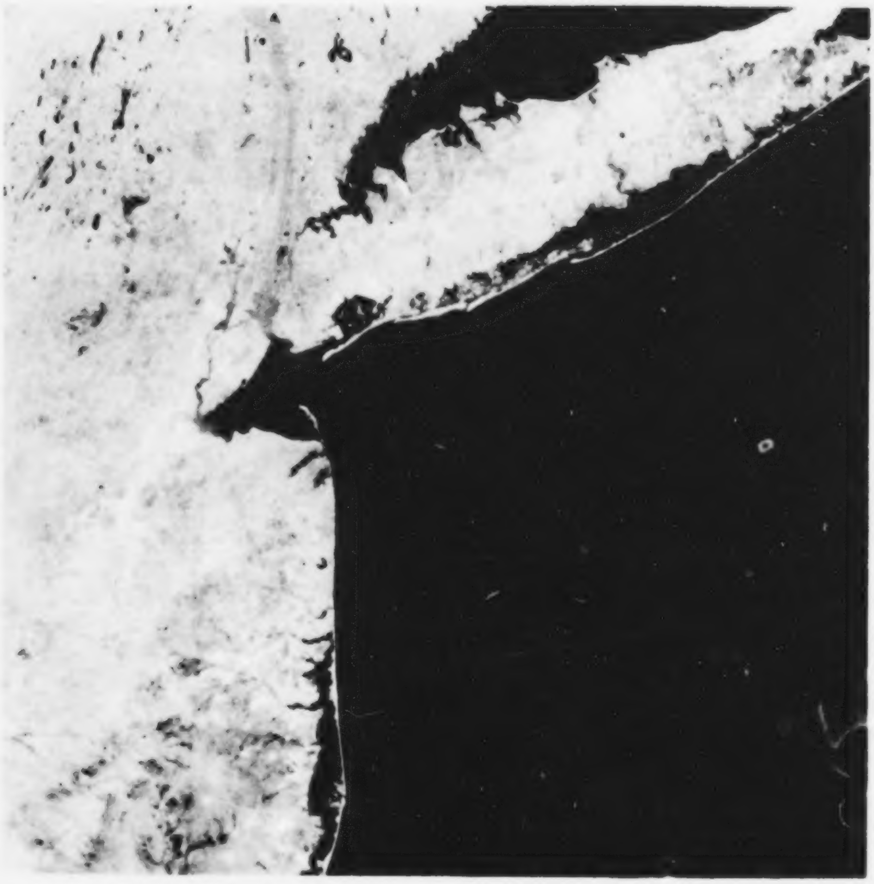
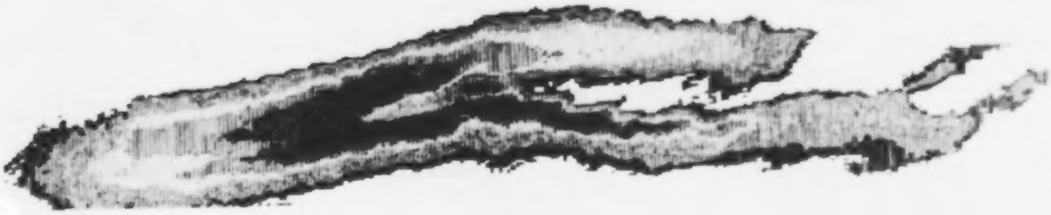


Figure 7. ERTS I imagery (BAND 5, 600-700 nanometers) of the New York Bight area on April 7, 1973.



FALSE COLOR MAP FROM MOCS DATA
NASA C-54 AIRCRAFT - ALTITUDE: 17500ft
AREA: 0.75 x 7.5 n mi
RED: HIGHEST ACID CONCENTRATION
BLUE: 60-65% OF HIGHEST CONCENTRATION

Figure 8. False color map of acid waste dump in New York Bight. The outer boundary is 50% of the acid strength in the center of the dump.

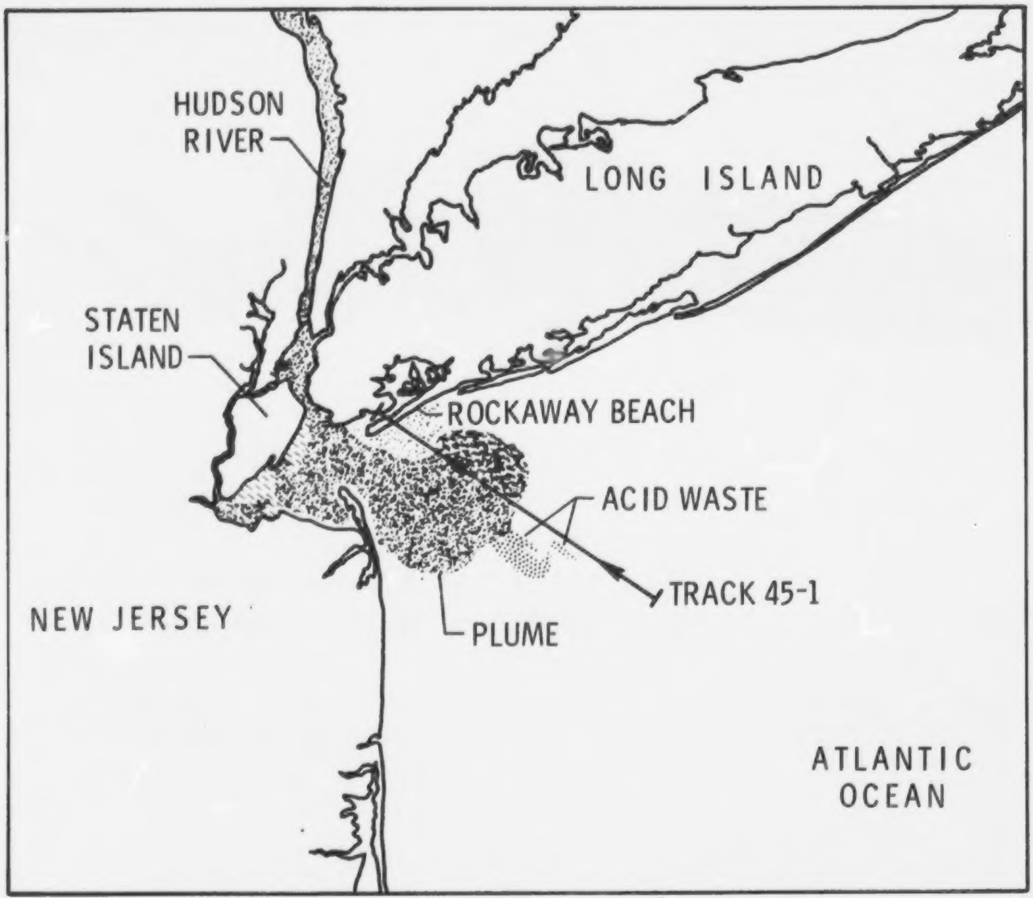


Figure 9. Sketch of the ERTS I imagery (Fig. 7) showing approximate boundaries of the plume, acid waste, and one track of the NASA C-54 aircraft.

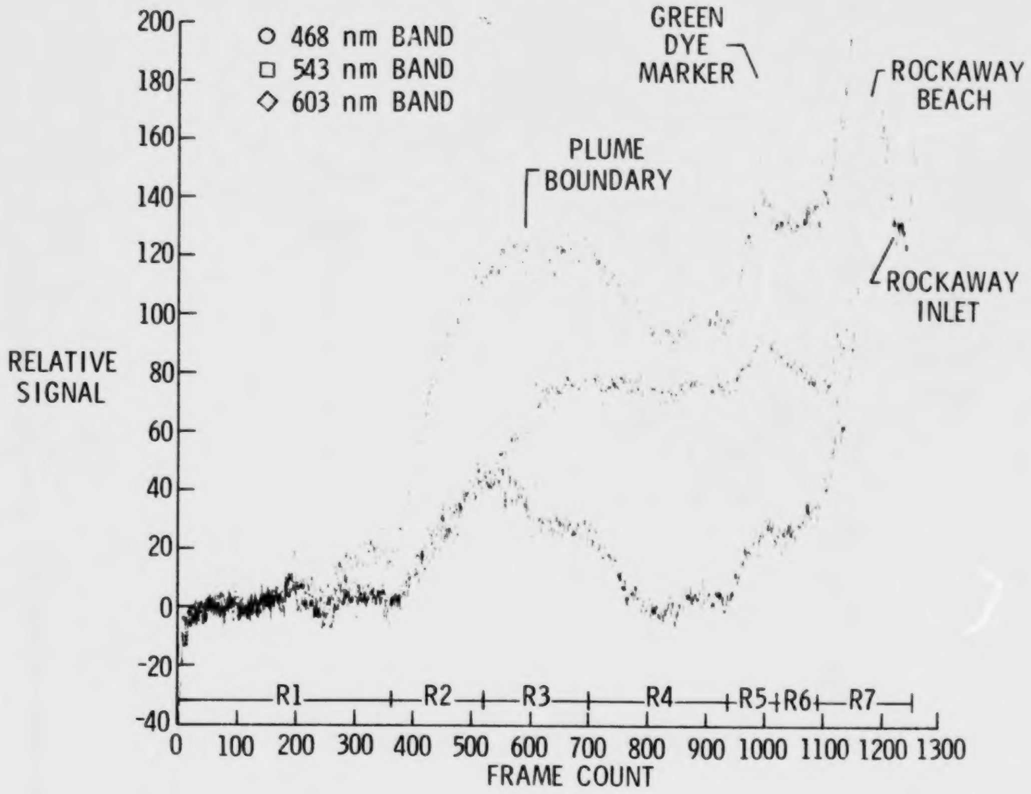


Figure 10. Relative signals along center of track 45-1 for three spectral bands. The signal levels have been adjusted such that upwelling light over blue water equals zero relative signal.

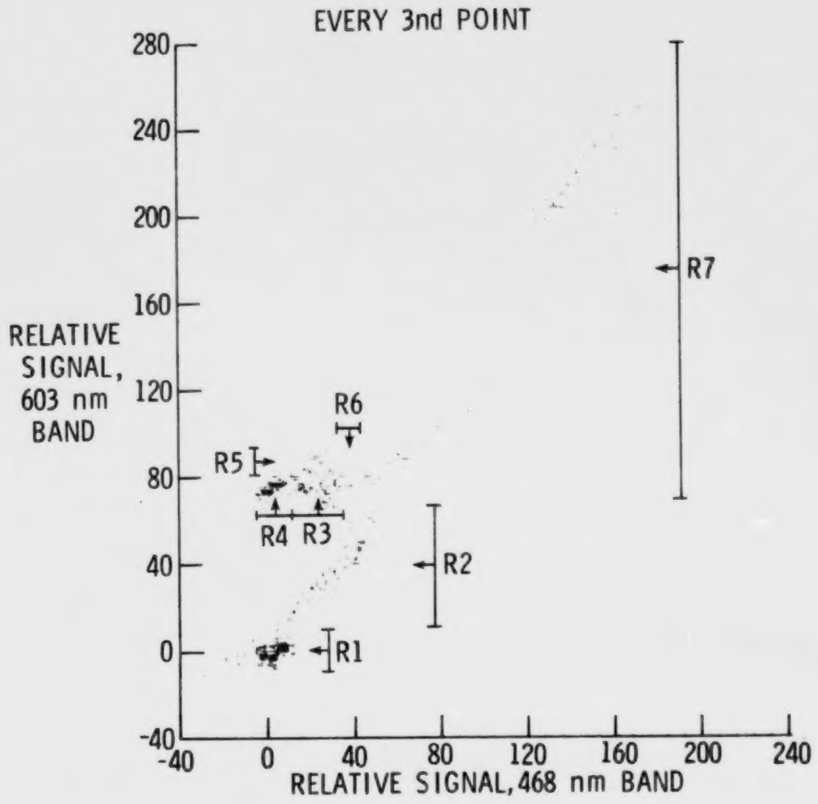


Figure 11. Relative signals of 603-nm band versus 468-nm band for data along track 45-1 in New York Bight. The regions designated in Figure 10 are approximated on this plot.

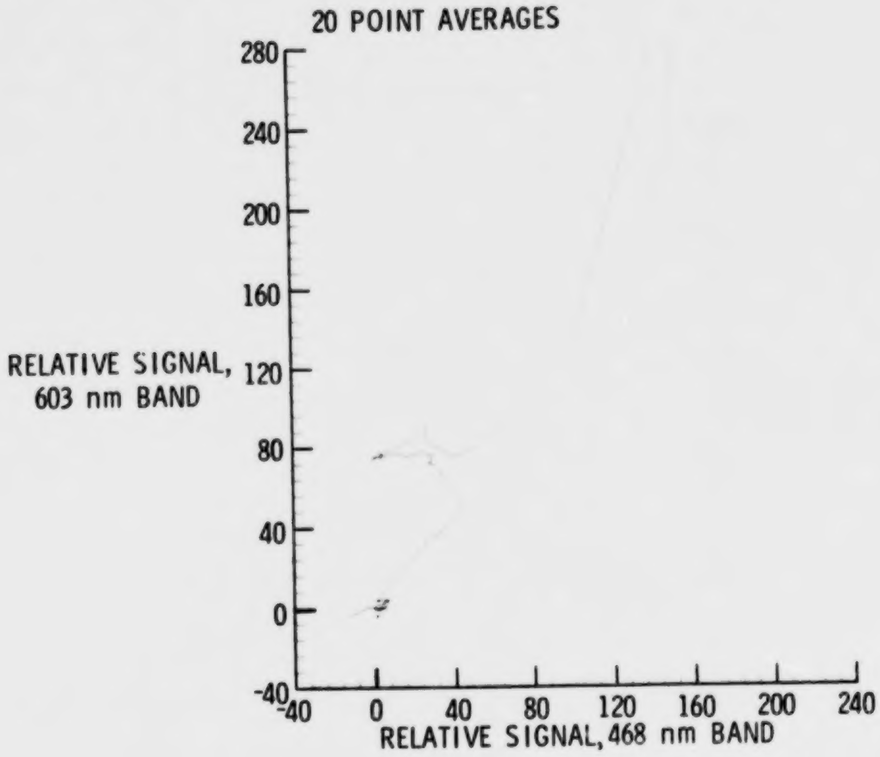


Figure 12. Relative signals of 603-nm band versus 468-nm band for data along track 45-1 in New York Bight. Lines are drawn between averages of consecutive sets of 20 data points.

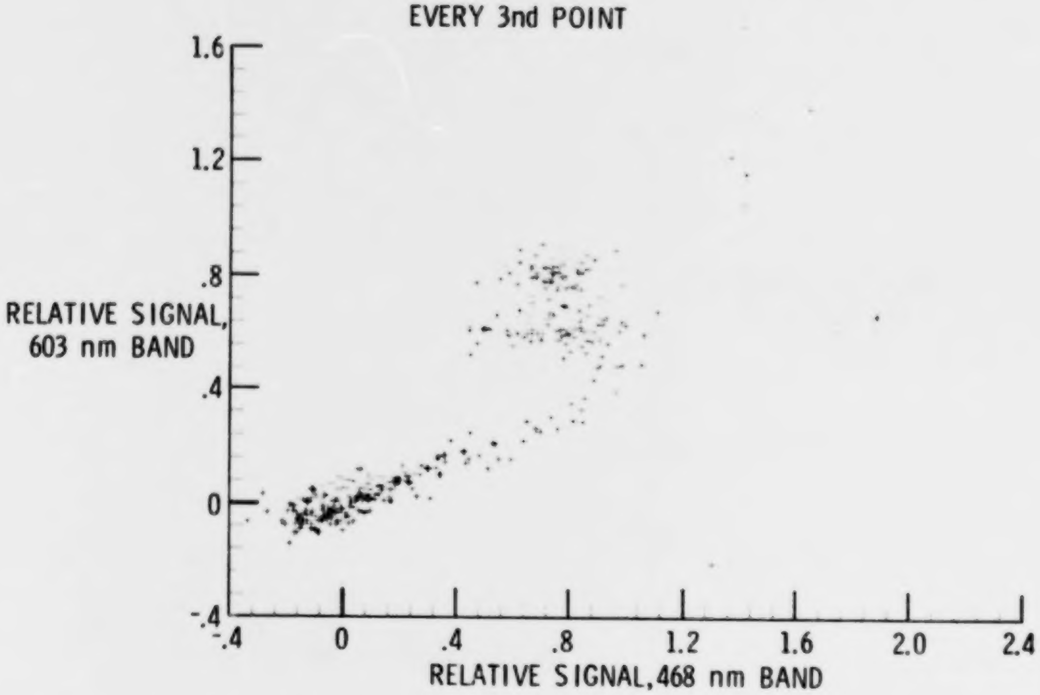


Figure 13. Relative signals of 603-nm band versus 468-nm band for data along 36° parallel track off Cape Hatteras. (Compare with Fig. 11.)

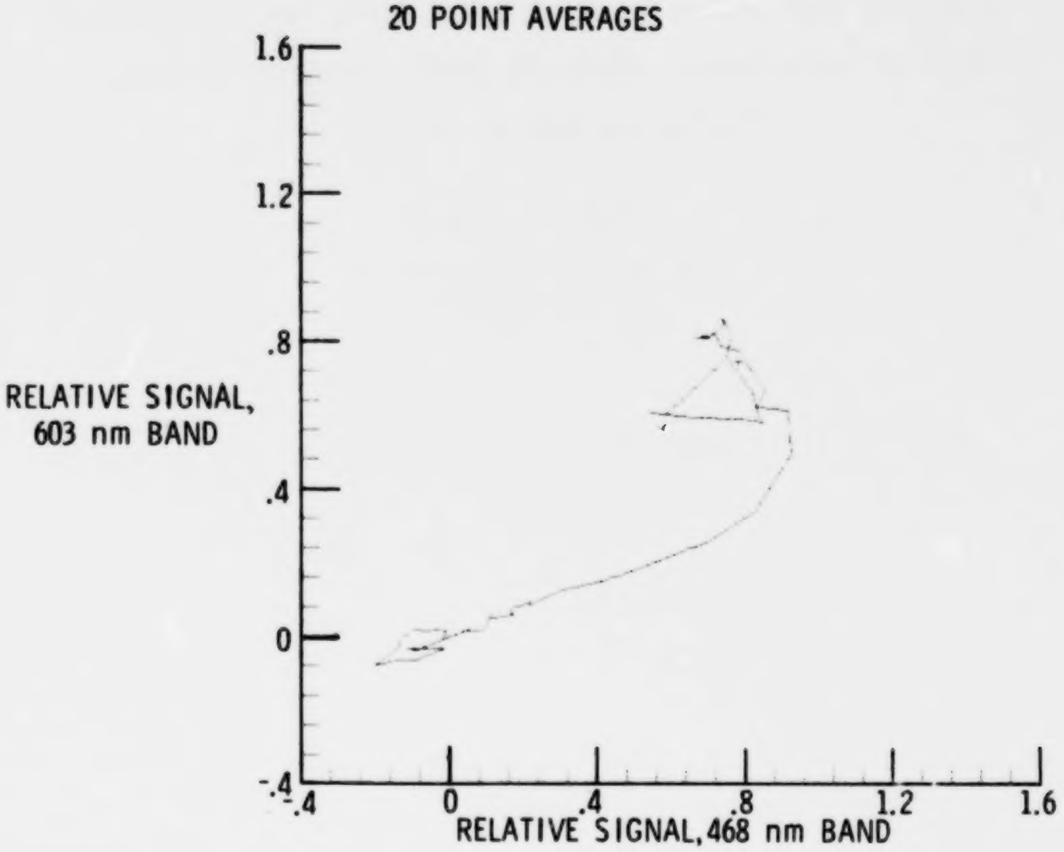


Figure 14. Relative signals of 603-nm band versus 468-nm band for data along 36° parallel track off Cape Hatteras. Lines are drawn between averages of consecutive sets of 20 data points. (Compare with Fig. 12.)

SUMMARY OF NASA LANGLEY RESEARCH CENTER REMOTE SENSING ACTIVITIES UNDER THE ENVIRONMENTAL PROTECTION AGENCY INTERAGENCY AGREEMENTS: POTENTIAL FOR REGIONAL APPLICATIONS

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Presented at the Second Environmental Quality Sensor Conference

Las Vegas, Nevada
October 10-12, 1973

SUMMARY OF NASA LANGLEY RESEARCH CENTER REMOTE SENSING ACTIVITIES UNDER THE ENVIRONMENTAL PROTECTION AGENCY INTERAGENCY AGREEMENTS: POTENTIAL FOR REGIONAL APPLICATIONS

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BIOGRAPHICAL SKETCH

Mr. Raper is a Senior Aerospace Engineer with 15 years experience in aerospace research projects at the Langley Research Center. He has managed or assisted in the management of projects involving reentry heat protection and communication, hypersonic transition, parachute qualification, and rocket motor qualification. In the last year he has managed the NASA/EPA Interagency Agreement for Water Pollution Sensor Evaluation. In addition to establishing a flight-test program to meet the needs of nine investigators, it was necessary for him to devise an interim capability for multispectral scanner data analysis and establish requirements and plans for a more permanent Langley capability. He has recently joined Langley's Environmental Quality Program Office with responsibility for managing studies to define sensor modules for future pollution monitoring satellites.

ABSTRACT

The purpose of this paper is to report the current status of all except three of the activities being conducted under the NASA/EPA Interagency Agreement for Water Pollution Sensor Evaluation. The three topics excluded, the multiwavelength laser, MOCS, and Pollutant Response, are separately reported in this session. A description of eight investigations is included. Expected applicability of these investigations to regional situations is described.

INTRODUCTION

Dr. Fletcher, the NASA Administrator, in his talk to the 37th Annual Meeting of the National Wildlife Federation, on March 17, 1973, said the following:

"No part of the changing, moving face of the globe we inhabit is free of human influence or removed from human interest. We therefore can afford to leave no part unmonitored. We need to know the condition of our environment and in time to take appropriate action." Many of the capabilities he described were identified as already possible; the technologies exist or are under development. He said, "We are learning to interpret and as we do so, we learn what other related parameters and phenomena we need to observe to get a total picture." Early in his talk, Dr. Fletcher pointed out to the audience that the systems

NASA is developing are just tools and must not be thought of as technological solutions in themselves to the serious environmental challenges, problems, and issues with which the world must cope. "The basic purpose of these tools," he explained, "is to collect and communicate data from which information can be extracted."

ERTS-1 and Skylab are two of our best known uses to date of these tools. There is also a large effort within NASA's Office of Applications to define applications for sensors within our pollution and earth resources programs. The AAFE (Advanced Applications Flight Experiments) program, Figure 1, at Langley is one such effort and has the objective of developing an effective inventory of space application experiments from which future missions and flight experiments for approved flights may be proposed. AAFE does in fact bring instrument techniques to the point where they can be applied to problems such as those faced by EPA. We are also interested in investigating with the User agencies the design of an aircraft remote sensing system to investigate the usefulness of synoptic measurements of air and water quality on urban and regional scales. Underscoring these Langley activities is the recent designation of Langley as NASA's Focal Center for Space Application's Environmental Quality monitoring. In this role Langley is responsible to coordinate the agency's pollution monitoring activities in a way which will most directly benefit agencies such as the EPA.

Defining remote sensor applicability for EPA mission requirements is the subject of the interagency agreement between EPA and NASA – in existence since June 1972 – and the status of work under the agreement is the subject of this paper. The interagency agreement, under the cognizance of Dr. Harvey Melfi of Las Vegas NERC and John Koutsandreas of EPA Headquarters, is designed to evaluate the applicability of various existing remote sensors for detecting and monitoring various types of water pollution. The agreement specifically directed investigations of pulsed laser systems, multichannel scanning radiometers, multiband cameras, infrared scanners, and second derivative infrared spectrometers. Subsequently, investigations in 12 areas were undertaken in support of these objectives. Reports of activity with the pulsed laser (Multiwavelength Lidar), the multichannel scanning radiometer (MOCS), and multiband cameras (Pollutant Response) are presented in the previous three papers. This paper will deal with summary status reports of activities to date in the other areas.

Before proceeding to a discussion of activities being conducted under the interagency agreement, it is important that three observations of an introductory nature be stressed. First, if such agreements are to provide maximum benefits within EPA it is necessary that more dialog exist between the agencies with regard to specific EPA mission requirements, the manner in which EPA field surveys are conducted, and EPA capabilities for data analysis. Second, as noted in Dr. Fletcher's talk, the basic purpose of the remote sensing tools is to collect and communicate data from which information can be extracted. Although there is some polishing to do on the collecting end of the present investigations, the most work remains in developing ways to extract information from the collected data relative to defining the water pollution situation quantitatively as well as qualitatively. Third, the use of remote sensing will probably never replace the requirement for selected in situ sampling. Remote sensing appears to best fit the situation where large areas are to be frequently covered and where the synoptic view is required to provide an evaluation of the interrelationships between factors being sensed. Remote sensing probably can best indicate where to concentrate the in situ sampling. Also, in situ sampling will continue to find application because the remote sensor may not be sensitive to the desired parameter or because of technical or economic constraints associated with providing the required spectral or spatial resolution.

SALINITY MAPPING

A 2.65-GHz S-band microwave radiometer has been developed as a part of Langley's AAFE program to remotely sense sea state. A byproduct of the data has been information about surface salinity. As indicated in Figure 2, the 2.65-GHz microwave radiometer is insensitive to salinity variation below about 10 ppt. Also, the sensitivity to salinity above 10 ppt does not meet measurement requirements. The 2.65-GHz radiometer was used, however, to demonstrate the salinity mapping concept and to provide confidence that a radiometer dedicated to salinity mapping could be built. As indicated in Figure 3, a 1.4-GHz L-band radiometer system would provide the required operational characteristics. If the 0.1 K accuracy in brightness temperature demonstrated in the 2.65-GHz system is maintained in the L-band system, a variation of 0.2 to 0.3 ppt of salinity change will be detected over the range of 3 to 35 ppt of salinity which is the operational range of interest to EPA. The L-band system is now being assembled and is expected to be ready for EPA demonstration flight tests in August 1974.

Figure 3 shows the type of salinity survey that EPA would be interested in conducting at periodic intervals. The map shown was produced by massive manual sampling using boats. A comparison of the resources required to sample just the lower half of the bay is presented along with the expected expenditure of resources when using the microwave radiometer remote sensing approach. The radiometer approach is equally applicable for monitoring changing conditions around a powerplant, around a desalinization operation, or due to a massive storm. Again, one of the obvious benefits of the salinity remote sensor is its ability to cover quickly and frequently a large area and provide a synoptic view of conditions with a small manpower expenditure.

Multispectral Scanner Detection of Algae

One of the principal EPA interests with regard to monitoring water quality involves detecting and monitoring water algae content. The amount of algae is indicative of the amount of waste nutrients being dumped into the water and is an indicator of the suitability of the water for human consumption, recreation, and wildlife. The purpose of this investigation was to use the multispectral scanner over an area of varying algae concentration to accomplish two objectives. The first is to determine the optimum spectral ranges which identify algae in the water and which permit computer separation of the algae from other features. The second is to determine whether it is possible to produce a quantitative map of algae content for a water body such as a tidal river. The NASA-JSC Earth Resources Program C-130 aircraft and 24-channel multispectral scanner were used to gather the data in October 1972 over the Patuxent River in conjunction with an intensive field survey of water parameters which was being conducted simultaneously.

Analysis of the data has proved to be a major task. Langley did not possess the capability for analysis of such imagery data and much effort has been devoted to developing that capability. The Purdue-LARS remote terminal located at the GSFC and the Bendix-Ann Arbor analysis systems have been used for the Patuxent River data analysis. Figure 4 shows the analysis approaches which can be used and points out the dependence of analyses on ground truth data. Figure 5 shows a portion of the Patuxent River and is the result of the supervised classification of the nonwater areas with the Bendix analysis system. The two dots along the upper bank of the river at the right side of the image are the boats from which the ground truth data were taken. Figures 6 to 11 present the results of supervised (since the features to match were specified even though not known) classifications of spectrally similar areas in the image. For each classification, the computer was instructed to locate other areas spectrally similar to a selected training site. A training site around the boat was selected because of the indicated high chlorophyll quantity, 140 mg/m^3. Individual examination of some of the 14 channels of multispectral scanner data indicated other spectrally different areas of water and thus a small portion of each was selected as a training site for classification of the image. An unsupervised classification of the total image area to define all the statistically different spectral classes has not yet been attempted.

Figure 6 is a water classification based on a training set taken at the boat and thus should contain all the area that responds spectrally as water containing 140 mg/m^3 of chlorophyll. Figure 7 is a water classification based on a training set taken at the outflow of the upper left stream into the river. Figure 8 is a water classification based on a training set taken in the inland body of water just behind the boat. Figure 9 is a water classification based on a training set taken in the river to the left of the boat. Figure 10 is a water classification based on a training set taken in the water at the left of the sand bar at the river bend. Figure 11 is a water classification based on a training set taken in the water in the center of the river at the left of the boat. The principal point which can be made with Figures 5 to 11 is that it is possible to use computer analyses to identify spectrally different classes of water. Unfortunately, not enough ground truth data exist with this set of data to identify each class of water. Future experiments will be planned with more ground truth so that a "calibration curve" can be constructed. The above comments infer that the different water classes are related to different amounts of chlorophyll which would permit contouring as desired. Much work remains to be completed to verify this relationship. Even though the specific multispectral scanner used in this investigation was never meant for operational use, the potential for this type of remote sensing device is great because of its ability to accurately define the spectral signature of a pollutant. An understanding of the multispectral scanner information will permit the development of efficient and economical sensors for many types of water pollutants and the understanding of information from other sensors.

For the immediate future more analysis of the present data will be performed, and other remotely sensed data taken simultaneously will be cross-correlated in an effort to develop means for identifying the water classes.

ERTS INVESTIGATIONS

Many of the investigations under the interagency agreement have quite naturally raised the question, "How applicable is current ERTS imagery to EPA water pollution monitoring requirements?" We know from present ERTS investigators' findings that the ERTS data indicate various water pollutants. This question is underscored by the importance of the synoptic view. There is also interest in how conclusions derived from ERTS data compare with those derived from ground truth and from aircraft remote sensors. Five separate investigations involving ERTS are in progress and each has the common objective of defining how to use ERTS data in combination with other remotely sensed and ground data to provide a water pollution detection and monitoring capability.

Lake Eutrophication – The National Eutrophication Survey is a major effort within EPA to define the eutrophic state of specific inland lakes throughout the United States. A significant output of that survey will be data to be used in constructing predictive computer models of the eutrophication process. The purpose of this ERTS investigation is to determine whether data can be provided by ERTS which will permit continuing evaluation of the eutrophic state of lakes and which can be used in the computer predictive models. Figure 12 presents the current status of this investigation. An ERTS-B proposal was submitted in January 1973 and will be revised to reflect a more complete problem definition and work plan prior to the proposal evaluations in January 1974.

Upper Bay Pollution – The types of water pollution found in a large bay surrounded by highly industrialized sites and cities is very different from that found in an inland lake. This investigation is directed at defining the applicability of ERTS to detecting and monitoring various water pollutants such as algae, sediment, oil, and sewage in a large bay area – the Chesapeake Bay. Figure 13 presents the current status of this investigation. An ERTS-B proposal was submitted in January 1973 and will be revised to reflect a more complete problem definition and work plan prior to the proposal evaluations in January 1974.

Land Fill Classifications – A problem of particular concern to the State of Pennsylvania and EPA, Region III is the proliferation of solid waste dumps throughout the state. Current laws regulate location and type of dump to a land fill operation. A means of detecting noncompliant dumps and for continuous surveillance of the operation of all others is required. This investigation is directed at evaluating to what extent ERTS data can be used in locating and monitoring land fills. Figure 14 presents the current status of this investigation. Early efforts directed at manual viewing of the magnified ERTS images proved inadequate, especially when attempting to determine if land fills or dumps existed in unrecorded locations. Subsequent analysis has depended upon the Purdue-LARS analysis approach for supervised classification. The computer training sets were defined by aircraft photographic imagery taken over known land fill locations. Results, to date, indicate that land fill sites as small as 10 acres can be detected in ERTS imagery. When a supervised classification of a large part of an image was performed to pick out land fills, only about 10% of the locations thus identified were actually land fills. This result probably occurred because the land fills are nonhomogenous spectrally and have limited unique features which are spectrally identifiable. Also too imprecise knowledge exists of what is and is not a land fill. Future analysis activities will concentrate on improving the degree of land fill recognition. The aircraft 24-channel multispectral scanner data will be analyzed for land fill identification to determine whether greater spectral resolution improves identification and to better define the spectral signature of a "typical" land fill.

Acid Mine Drainage – EPA (Region III) and the States of Pennsylvania and West Virginia are particularly affected by seepage from shaft and open coal mines into the surrounding streams. The resulting acid stream causes destruction of adjacent vegetation. Knowledge of the source of the seepage is required in order to enforce present laws or to take measures to prevent seepage from abandoned mines. The purpose of this investigation is to determine the most cost effective system for detecting and monitoring the effects and extent of acid mine drainage using ERTS as appropriate. ERTS should be most effective in providing a synoptic view and in identifying large areas of vegetation destroyed by acid mine drainage. ERTS is not expected to be able to monitor the water quality in small streams. This will perhaps only be possible with manual in situ sampling. Figure 15 presents the current status of this investigation. The primary effort is contractual and the contractor will present a detailed paper elsewhere in these proceedings. Figure 16 outlines the contractual tasks. The emphasis on land use arises from the fact that land use maps do not exist for the selected test area and from the requirement to correlate land use with acid mine drainage effects. Figure 17 indicates the test site location chosen for this study, which is the head waters for the Potomac River. The rectangular outline indicates coverage provided by a recent ERTS underflight mission. The end effort of the contract is to define the optimum mix of sensing techniques for performing the required monitoring. It will remain for future contracts, NASA-LaRC, or EPA programs to evaluate the proposed technique.

Data Automation and Transmission - In order to be in a position to react quickly to a pollution problem, one must receive monitoring information rapidly and continuously and in a form which is readily assimilated. At the present time EPA (Research Triangle Park NERC) is receiving raw, air quality monitoring data weekly in magnetic tape form. Technology exists for automating the conversion of these data into a readily understandable form and for transmitting the information twice daily to a selected location. The ERTS Data Collection Platform is in fact specifically designed for this type of data relay. The purpose of this investigation, see Figure 18, is to demonstrate this technology by installing an automation/transmission system in the District of Columbia CAMP station. Even though air quality parameters will be monitored, the system to be demonstrated will be equally applicable to water quality parameters. Figure 19 summarizes the requirements that the system is being designed to accommodate. Figure 20 presents a schematic of the present CAMP station arrangement and the proposed noninterference automation/transmission system. For the system demonstration, the data handling and converting computer is being placed in the CAMP station in order to centralize the total effort into one location. In an operational arrangement, data from a number of monitoring stations could be transmitted to a single site where the computer is located.

SOUTH RIVER SEWAGE OUTFLOW DETECTION

Large portions of the South River in Maryland are presently closed to fishing because of the presence of coliform bacteria from private septic tank seepage into the river. Personnel in the Anne Arundel County Health Department are responsible for eliminating the septic tank violations and for patrolling the approximately 430-mile perimeter of the South River at periodic intervals to verify no further violations. The purpose of this investigation is to determine what, if any, remote sensing techniques exist which will enable the Health Department to detect violations by checking at frequent intervals. The approach to date has been to use various films and filters, a radiation thermometer, and a thermal IR scanner over known outfall locations in an attempt to identify an approach for further study. Manual viewing of the films has been inconclusive. Density slicing of the same film will be performed in the near future. The thermal IR scanner used proved not to have the required resolution for detecting small outflows, even at the low flight altitudes employed. Future missions with a different

IR scanner are planned. The potential for application of remote sensing to this problem is fairly obvious; however, the sensors on hand which have been tried may not possess the required spatial resolution for such a small seepage as that which one might expect from a private septic tank.

CONCLUDING REMARKS

Our experience to date with investigations being performed as a part of the NASA/EPA interagency agreement strongly underscore Dr. Fletcher's comments about having the tools but not yet fully understanding how to get information from the data. Developing methods for getting this information will be the most important benefit for EPA. Also emphasized by our experience is the critical importance of ground truth data for developing an understanding of the sensors capabilities. Finally, this paper has tried to show in various ways that remote sensing will not replace present methods of manual sampling. It is more likely to raise enough questions which will require increased manual sampling. Most importantly, such sampling will not be random but will be at specific locations where problems are indicated.

ACKNOWLEDGMENTS

Acknowledgment is hereby made to the following Langley employess whose work was summarized herein: Bruce M. Kendall, Ruth I. Whitman, Robert W. Johnson, John B. Hall, Joseph W. Drewry, and James N. Chacamaty.

OBJECTIVES

- TO DEVELOP AN EFFECTIVE INVENTORY OF SPACE APPLICATION EXPERIMENTS FROM WHICH FUTURE MISSIONS AND FLIGHT EXPERIMENTS FOR APPROVED FLIGHTS MAY BE PROPOSED

APPROACH

- FUND THE DEVELOPMENT OF SELECTED EXPERIMENTS, BEGINNING AT A STAGE WHEREIN THE APPLIED RESEARCH AND ENGINEERING FEASIBILITY HAS BEEN ESTABLISHED AND LEADING UP TO, BUT NOT INCLUDING THE PRODUCTION OF PROTOTYPE HARDWARE

STATUS

- INITIATED IN FY '70
- 54 INSTRUMENTS FUNDED TO DATE
- 11 INSTRUMENTS TO BE FLOWN IN AIRCRAFT MISSIONS
- 6 INSTRUMENTS DEMONSTRATED IN AIRCRAFT MISSIONS
- 23 INSTRUMENTS SELECTED OR BEING CONSIDERED FOR SATELLITE MISSIONS
- 14 INSTRUMENTS CURRENTLY UNDER DEVELOPMENT

Figure 1. Advanced applications flight experiments.

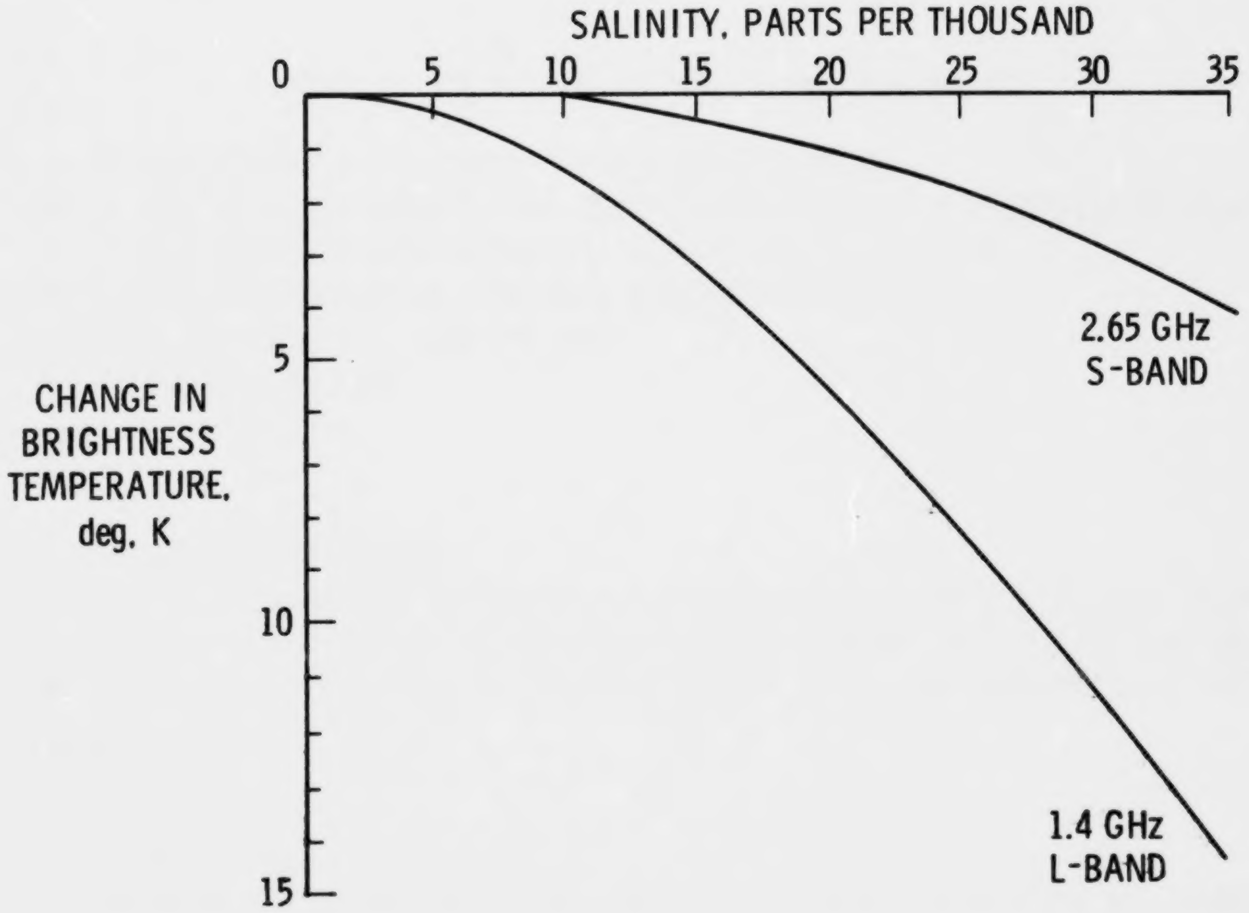
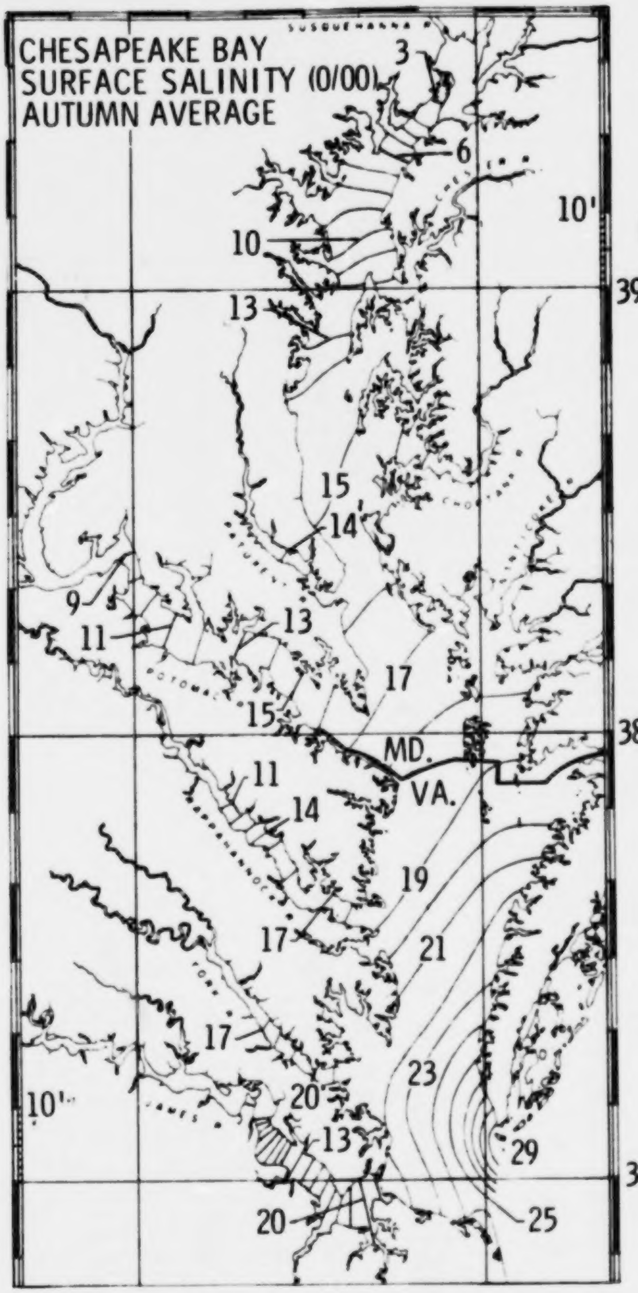


Figure 2. Microwave radiometer, change in brightness temperature with change in salinity.



SALINITY SURVEY OF
CHESAPEAKE BAY
AND TIDAL RIVERS

LOWER BAY REQUIRES:

- 80 BOATS
- 160 MEN
- 129 STATIONS
- 2 DAYS

OR

- 2 MEN
- 2 DAYS
- 129 STATIONS
- HELICOPTER

WHOLE BAY
WILL REQUIRE:

- 1 DAY
- 2 MEN
- AIRCRAFT W/MICROWAVE RADIOMETERS

Figure 3. Map of Chesapeake Bay showing average salinity variations of autumn.

- SUPERVISED CLASSIFICATION
  - ● IDENTIFY ALL PARTS OF THE IMAGE WHICH ARE SPECTRALLY SIMILAR TO THIS AREA WHICH GROUND TRUTH HAS IDENTIFIED

- UNSUPERVISED CLASSIFICATION
  - ● SEPARATE ALL PARTS OF THE IMAGE INTO SPECTRALLY SIMILAR AREAS AND WHICH WILL BE IDENTIFIED AT A LATER DATE

Figure 4. State of the art in MSS data analysis demands complete dependence on ground truth.

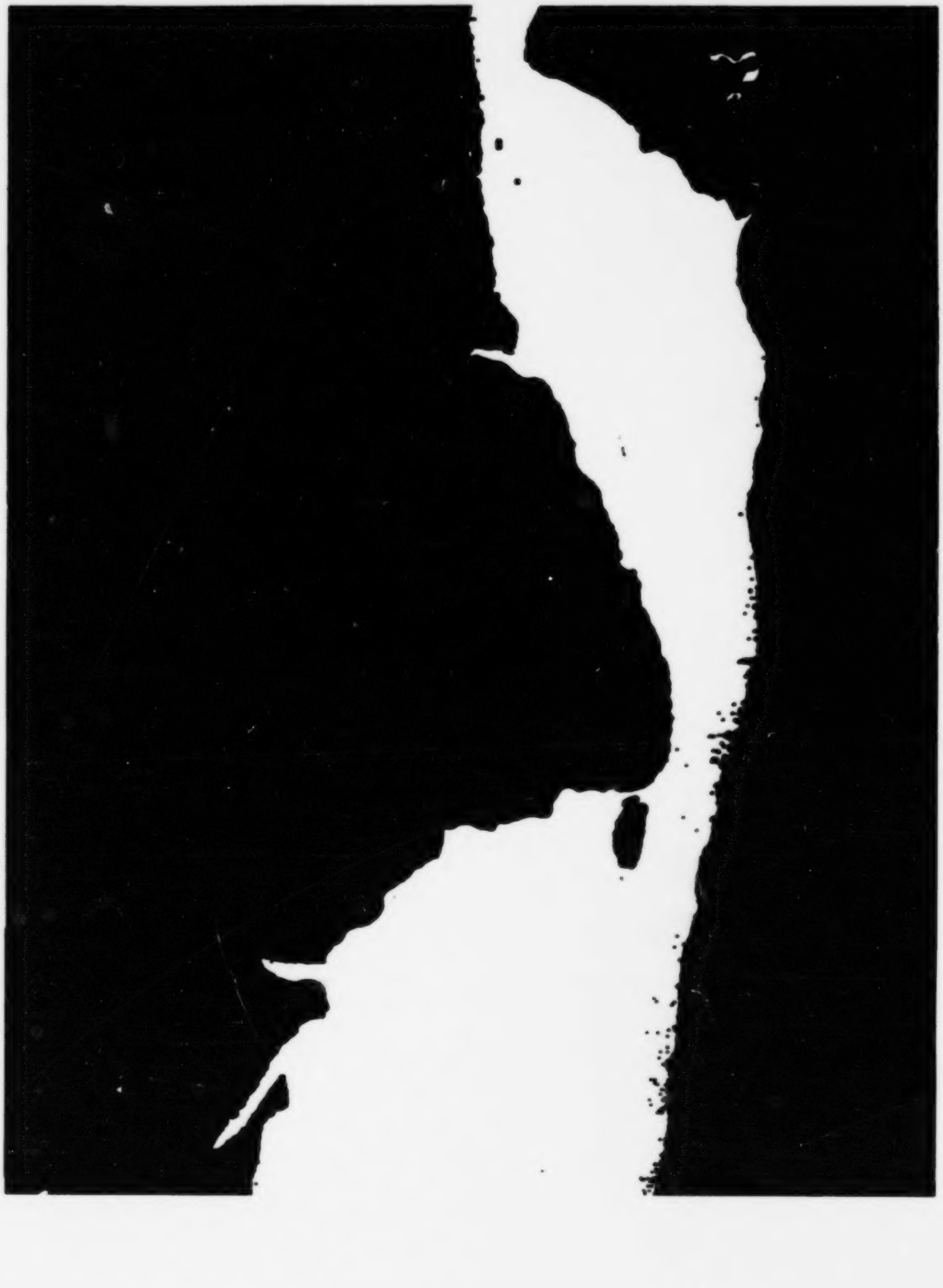


Figure 5. Patuxent River multispectral scanner data.

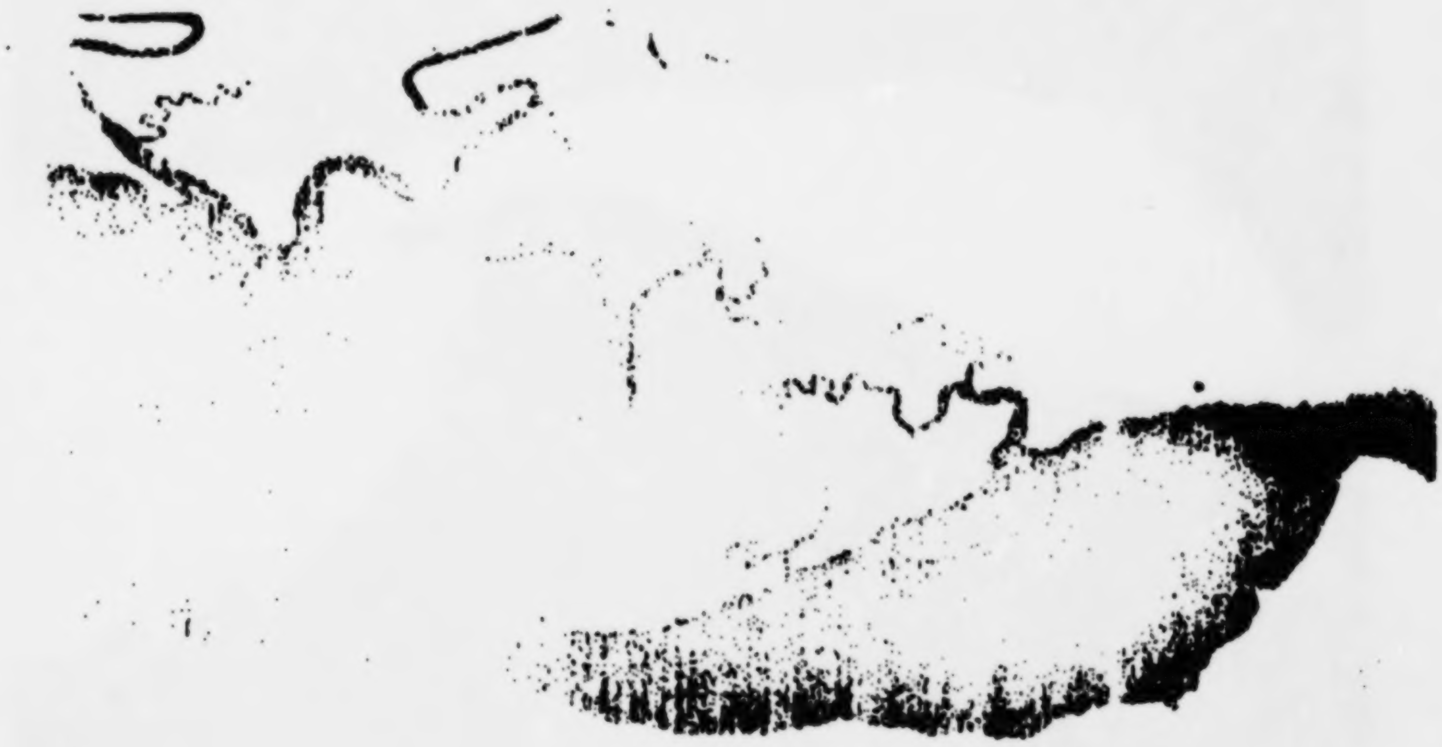


Figure 6. Patuxent River – training set taken at boat.

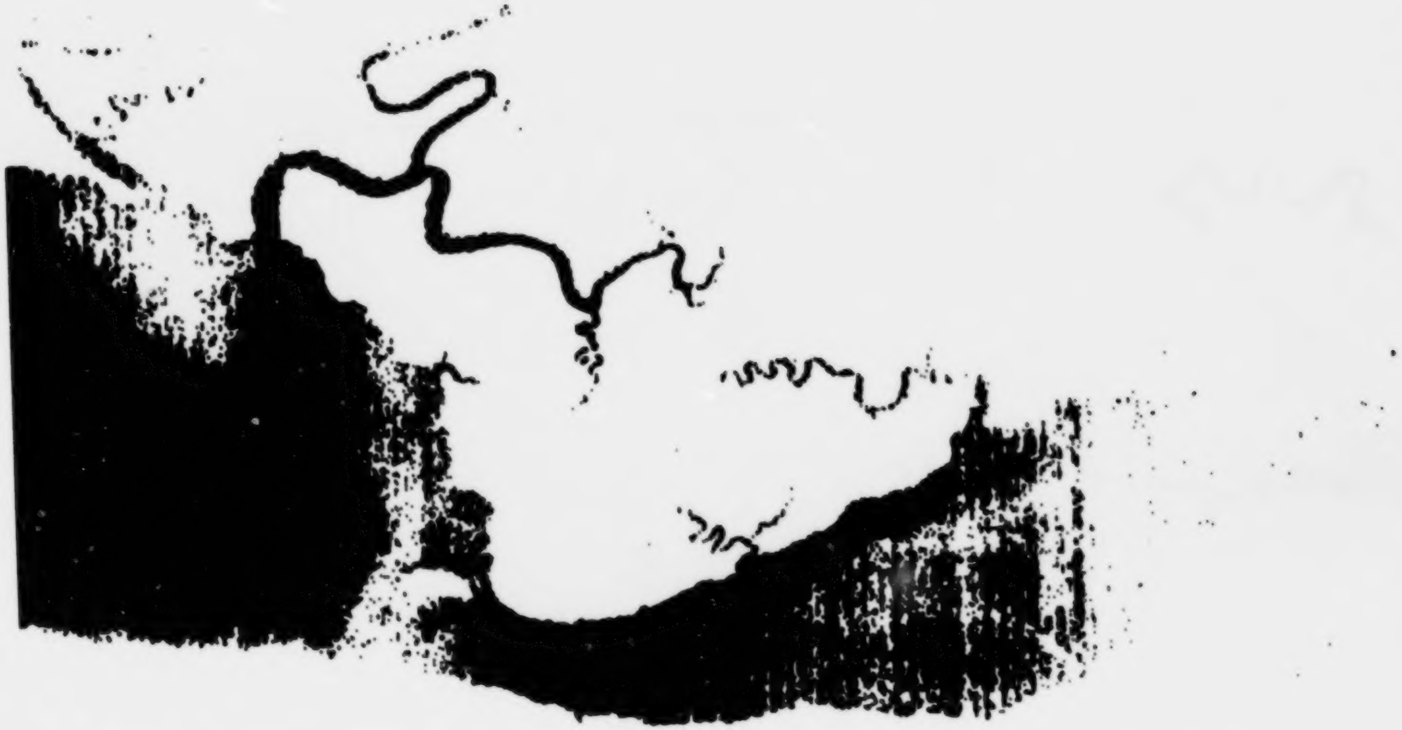


Figure 7. Patuxent River — training set taken at entry of upper left stream into river.

Figure 8. Patuxent River – training set taken in inland body of water behind boat.

Figure 9. Patuxent River – training set taken in the river to the left of the boat.

Figure 10. Patuxent River — training set taken in the water at the left of the river bend sand bar.

Figure 11. Patuxent River – training set taken in the water in the center of the river at left of boat.

OBJECTIVE - TO DEFINE :
- CURRENT STATE OF EUTROPHICATION - UTILIZING ERTS
- WATER SHED USE, WATER USE
- NUTRIENT CYCLE

STATUS -
- ONE AIRCRAFT PHOTO MISSION SIMILTANEOUS WITH NES AND ERTS OVER
  - KERR LAKE
  - LAKE CHESDIN
  - CHICKAHOMINY LAKE
- ERTS 1 IMAGERY BEING PROVIDED AUTOMATICALLY
- DATA ANALYSIS UNDERWAY
- ERTS B PROPOSAL PENDING

OUTLOOK -
- EVALUATION OF SEASONALITY EFFECT
- PROGRESS REPORT - JANUARY ' 74

COORDINATION - EPA, LAS VEGAS NERC

Figure 12. ERTS – lake eutrophication.

OBJECTIVE -
- STATE OF EUTROPHICATION
- INPUTS TO EXISTING POTOMAC AND PATUXENT MODELS
- STATISTICAL CORRELATION - ERTS AND EPA SAMPLING
- LOCATE POLLUTION SOURCES AND OUTFALLS

STATUS -
- DEVELOPING FIELD TEST PROGRAM
- EVALUATING PRESENT SENSORS FOR QUANTITATIVE RESULTS
- ERTS 1 IMAGERY BEING PROVIDED AUTOMATICALLY
- DATA ANALYSIS UNDERWAY
- ERTS B PROPOSAL PENDING

OUTLOOK - PROGRESS REPORT - APRIL 1974

COORDINATION - EPA, REGION III ANNAPOLIS FIELD OFFICE

Figure 13. ERTS – upper Chesapeake Bay pollution.

OBJECTIVE - DEFINE UTILITY OF ERTS FOR LOCATING AND CLASSIFYING LANDFILLS AND OTHER UNIQUE LAND SURFACE USES

STATUS -
- THREE AIRCRAFT PHOTO MISSIONS FLOWN
- CORRESPONDING ERTS IMAGERY OBTAINED
- DATA ANALYSIS UNDERWAY

ANALYSIS SEQUENCE -
- SITE LOCATION - PHOTO AND COUNTY MAP
- GRID MAP
- ERTS MSS DATA ANALYSIS VIA LARS

RESULTS -
- SELECTION RATIO - 10%
- SIZE - 10 ACRES

PROBLEMS -
- EDGE EFFECTS
- NON-HOMOGENOUS
- UNIQUENESS

OUTLOOK -
- FURTHER LARS TERMINAL ANALYSIS
- PROGRESS REPORT - APRIL '74

COORDINATION-EPA, REGION III HEADQUARTERS

Figure 14. ERTS – landfill classification.

OBJECTIVE - TO DEFINE MOST COST EFFECTIVE SYSTEM FOR DETECTING AND MONITORING EFFECT AND EXTENT OF ACID MINE DRAINAGE UTILIZING ERTS AS APPROPRIATE

STATUS -
- CONTRACT EFFORT UNDERWAY AND CONTINUING
- PRIOR DATA BEING ASSEMBLED
- ONE NEW AIRCRAFT MISSION FLOWN
- ERTS 1 IMAGERY BEING PROVIDED AUTOMATICALLY

OUTLOOK -
- RESULTS OF DATA REVIEW PHASE DUE NOVEMBER ' 73
- RESULTS OF DATA ANALYSIS PHASE DUE FEBRUARY ' 74
- FINAL CONTRACTOR ORAL PRESENTATION APRIL ' 74

COORDINATION - EPA, REGION III HEADQUARTERS

Figure 15. ERTS – acid mine drainage.

SURVEY AREA: WEST VIRGINIA - POTOMAC RIVER BASIN

TASK 1. DATA SURVEY (2 MONTHS)

a) REMOTE SENSING - AIRCRAFT AND SPACECRAFT
b) IN SITU MEASUREMENTS
c) LAND RECORDS

TASK 2. DATA ACQUISITION AND ANALYSIS (4 MONTHS)

a) IDENTIFY LAND USE ACTIVITIES
b) LOCATE AREAS AND POINT SOURCES OF POLLUTION
c) TOPOGRAPHY DISTURBANCES
d) DRAINAGE PATTERNS AND POLLUTANTS

TASK 3. DEMONSTRATION PROGRAM PLAN (2 MONTHS)

a) OPTIMUM SURVEILLANCE PROGRAM
b) CONTRACTOR'S REPORT

Figure 16. Contract effort.

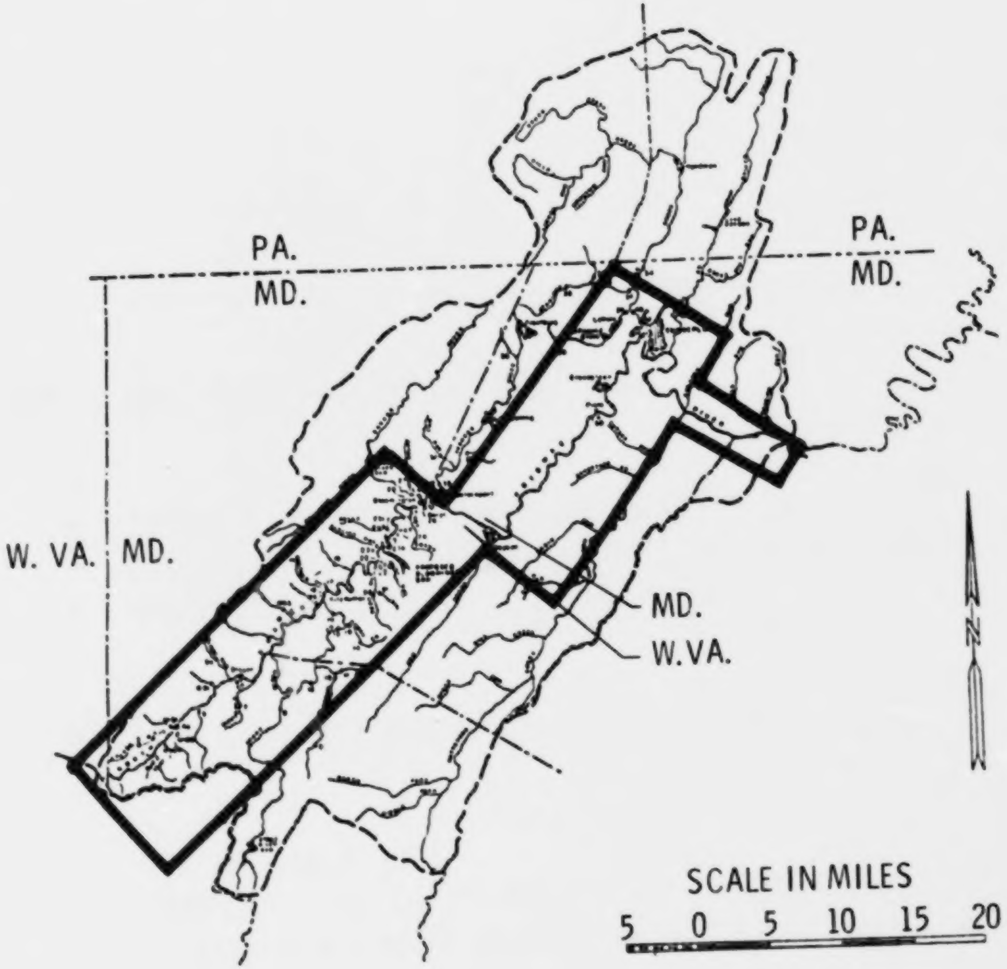


Figure 17. Mine drainage pollution study – north branch Potomac River.

OBJECTIVE - TO DEFINE AN APPROACH FOR AUTOMATING THE CONVERSION OF IN-SITU POLLUTION MEASUREMENTS INTO ENGINEERING UNITS AND TRANSMITTING THESE DATA TO A CENTRAL DATA COLLECTION POINT VIA THE ERTS DCP

STATUS -
- CONTRACT STATEMENT OF WORK COMPLETE

OUTLOOK -
- CONTRACT AWARD BY JANUARY ' 74
- COMPLETION OF SYSTEM DEFINITION TRADE STUDIES MARCH ' 74
- START SYSTEM CHECKOUT NOVEMBER ' 74

COORDINATION - EPA, RESEARCH TRIANGLE NERC

Figure 18. ERTS – data automation and transmission.

SENSORS

- SEVERAL SENSORS ARE REQUIRED TO DETECT POLLUTANTS AND MONITOR METEOROLOGICAL CONDITIONS

DATA VALIDATION

- ROUTINE CALIBRATION
- DETECTION AND CORRECTION OF SENSOR FAILURE

CALCULATIONS

- CONVERSION AND AVERAGING FOR EPA STANDARD

DATA AVAILABILITY

- ON SITE
- AEROMETRIC DATA BANK AT EPA
- RESPONSE TO LOCAL AND STATE REQUESTS

DATA TRANSMISSIONS

- DISTRIBUTION TO LOCAL USERS
- TO CENTRAL FACILITY OF MULTISTATION NETWORK
- FROM REMOTE SITE
- TO EPA DATA BANK

Figure 19. Operational requirements for in situ air quality monitoring.

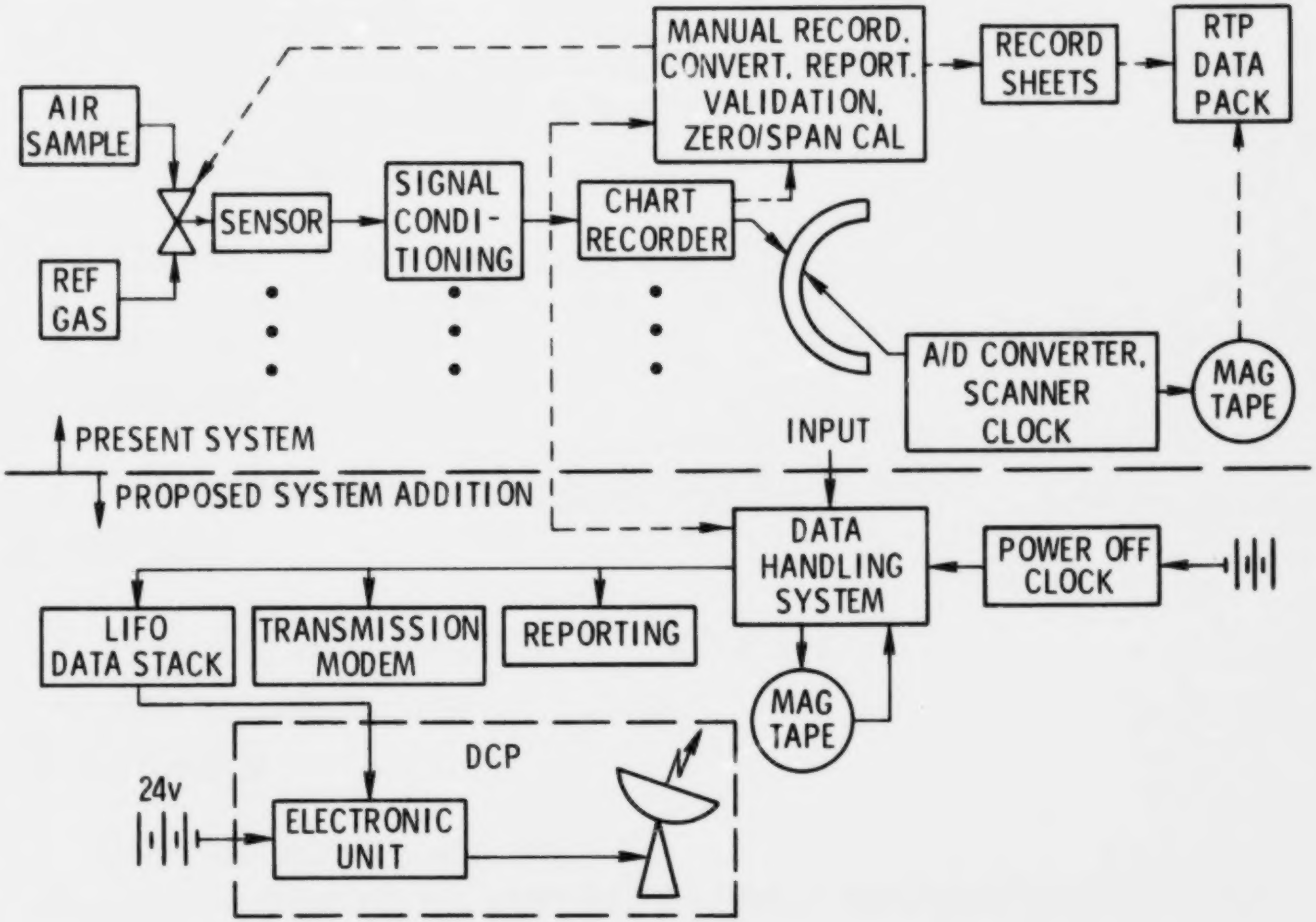


Figure 20. Data flow at camp and proposed system addition.

THE USE OF NEAR-INFRARED REFLECTED SUNLIGHT FOR BIODEGRADABLE POLLUTION MONITORING

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NASA Langley Research Center
Hampton, Virginia

and

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Annapolis, Maryland

Presented at the EPA Second Environmental Quality Sensors Conference

Las Vegas, Nevada
October 10-12, 1973

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BIOGRAPHICAL SKETCH

Mr. Bressette is a Senior Research Scientist with 25 years experience in aerospace research, all at the Langley Research Center, including research in the areas of visibility and thermal control of aerospace vehicles, passive communications, geometric geodesy, solar energy collection, and broadband photometric observation of satellite surfaces. In recent years, he has applied his research skills and background knowledge in scattering, absorption, and transmittance of electromagnetic radiation to applications of remote sensing of water pollution problems.

Dr. Lear, a graduate of the University of Rhode Island's Advance School of Oceanography, is presently Chief of the Biology Section at the EPA Annapolis Field Office. His responsibilities in EPA include surveillance of the waters of the Chesapeake Bay and its tributaries. He has had many years experience in sampling, analyzing, and reporting of water quality conditions in the Chesapeake Bay area.

ABSTRACT

On October 2, 1972, a pattern of chlorophyll a-containing phytoplankton (algae) was detected from 3 kilometers altitude in a series of near-infrared photographs of the Potomac River "Salt Wedge Area." Densitometer traces over the film images, related to in situ measurements of chlorophyll a concentrations that varied from 4 to >3000 μg/ℓ, revealed a phytoplankton "bloom" threshold in the near infrared between the concentration of 34 and 51 μg/ℓ.

The photography also revealed bottom features through 2 meters of water and made it possible to integrate chlorophyll a concentrations over a 16-square-kilometer area to demonstrate this remote sensing technique for biodegradable pollution monitoring.

INTRODUCTION

The NASA Langley Research Center is working with the Environmental Protection Agency, Office of Monitoring, in a joint program with the purpose of developing the capability to determine synoptic pollution levels and distributions of biodegradable pollutants through the use of a chlorophyll detection system. The objectives of the program are: first, to determine if the spatial and temporal changes of the chlorophyll produced by the growth of phytoplankton (algae) can be measured remotely, and second, to determine if these measurements can be employed in an index of the stress on the ecosystem caused by biodegradable pollutants.[1] The program will then develop a large area chlorophyll detection system (aircraft and satellites are to be considered) to be coupled with in situ measurements to provide the necessary synoptic observations required for biodegradable pollution monitoring and control.

The remote sensing approach that we have chosen is broad-band optical filtering of reflected sunlight from an altitude sufficiently high so that a synoptic view can be obtained. It is envisioned that a broad-band optical filtering system consisting of more than one broad-band filter will be required to separate phytoplankton reflectance from suspended sediment reflectance. At the present time photographic film is being used as the sensor in order to develop the optical filter system. However, in a biodegradable pollution monitoring mode the developed broad-band optical filtering system will be adapted to an electronic readout sensor; perhaps, solid state readout by silicon diodes, thus providing a rapid readout system most responsive to EPA's monitoring requirements.

THEORY

Sunlight reflected from plants that contain chlorophyll varies as a function of wavelength as shown by the solid curve in figure 1.[2] The generally accepted color classification for the various wavelengths is also shown along the abscissa for comparison. The reflectance of chlorophyll-containing plants is approximately 0.05 in the violet and blue region, increases to 0.15 in the green region, decreases to 0.05 in the orange and red regions, and then increases abruptly to 0.5 to 0.6 in the near-infrared (NIR) region. Since the human eye is unable to detect NIR, chlorophyll-containing plants are predominantly visible in the green region of the spectrum. However, NIR sensors can detect the spectral region where the high reflectance of chlorophyll-containing plants results in the greatest reflected solar energy.

To detect phytoplankton floating below the surface of water, the absorption of light by the water must be considered. The dashed curve in figure 1 is the exponential (1/2.7) absorption attenuation length of sunlight in distilled water as a function of wavelength, as obtained from reference 3. Thus, the penetration of sunlight in distilled water is approximately 27 meters in the blue region of the solar spectrum, decreases to 16 meters through the green region, and is a meter or less in the NIR region.

Comparing the reflectivity of chlorophyll-containing phytoplankton with the absorption of sunlight by water in figure 1 shows that when phytoplankton is within the upper meter or on the surface of the water, it can be detected in the NIR region. It is also probable that the magnitude of the reflected solar energy in the NIR will also depend upon the concentration of phytoplankton in the water as has been shown by Duntley for the green and yellow regions.[4]

EXPERIMENTAL AREA

On October 2, 1972, between the hours of 11:58 a.m. and 12:17 p.m. e.d.t., a photographic mission was flown at 3 kilometers altitude over the Potomac River "salt wedge area," a distance along the river of approximately 30 kilometers by an NASA, Wallops Station, C-54 aircraft. The flight lines are shown in figure 2. The tidal action in this area, where the salt water normally interfaces with the fresh water inflow, retards the fresh water flow, deposits some of the suspended sediment, and concentrates nutrient wastes from the sanitation plants located up river. Since the late 1930's waste water discharges in the Washington metropolitan area have increased the nutrients in the Potomac River - phosphorus has increased tenfold, and nitrogen fivefold.[5] These nutrients under spring and summer conditions result in massive "blooms" of phytoplankton (blue-green algae, primarily Anacystis cyanea), from Gunston Cove to Maryland Point. Below Maryland Point and above the Route 301 Potomac River Bridge the amount of phytoplankton decreases abruptly, primarily because of increased salinity and a decrease in nutrients.[5] On October 2, 1972, personnel from EPA, Annapolis Science Center, who obtained the in situ water measurements of chlorophyll a, light penetration, salinity, etc. (tabulated in Table 1), reported that in some places heavy concentrations of phytoplankton were visible on the water.

EXPERIMENTAL METHOD

The Wallops aircraft contained a bank of four Hasselblad cameras. Pertinent information concerning cameras, film, filters, and exposure are listed in Table 2. Three of the Hasselblad cameras were equipped with the Wratten filter selections shown in figure 3 where transmittance as a function of wavelength is plotted for the three filters.[6] The number 58 filter transmits reflected sunlight only under the curve in the blue-green-yellow region. The number 12 filter transmits reflected sunlight under the curve in the green-yellow-orange-red region with the cutoff in the red determined by the film used (Table 2). The number 89B filter transmits reflected sunlight under the curve in the NIR region with the cutoff again determined by the type of film used (Table 2).

Black and white film, which was used in this experiment, was flown with all three filters. In addition, a Hasselblad camera was used with conventional color film and a haze filter to provide color reference. The film-filter systems just described were selected to isolate the green and NIR reflectance of phytoplankton as identified in the theory section of this paper as well as to identify other color features such as the red Maryland clay on the river bottom. The four cameras were synchronized; this resulted in four sets of photographs (28 photographs per set).

RESULTS AND DISCUSSION

As predicted from our preliminary study, the photographs taken through the NIR filter on black and white film revealed many features in or on the water that contrast strongly with the background of the water as shown in figure 4. Pictures 1 through 7 which show many features in the water are from the flight line of the upper reach of the river where the in situ data indicated very high chlorophyll a concentrations and very low salinity. Pictures 9 through 15 are from the flight line over the "salt wedge area," and as can be seen in pictures 10, 11, and 12, the features are concentrated on the side of the river opposite the salt water intrusion for the flood tide conditions existing at the time of these pictures. Along the flight line over the lower reach, pictures 17 through 22, where the salinity is above six parts per thousand, the features are absent and the water is uniformly black, with some increased radiance in places from sun-glint, shallow bottom areas, and powerplant smoke. The consistency of the quantity of features within the fresh water area and the very high in situ measurements of chlorophyll a in the same area identify the features in the water in pictures 1 through 14 as chlorophyll a-containing phytoplankton.

The positive prints that are seen in figure 4 were obtained by overdevelopment from a normally developed negative that, in turn, was obtained with a camera setting that was one full stop open from the recommended Kodak opening for the camera shutter speed, sun angle, and altitude of the flight mission. As you can see in all the prints, the solid white areas, which are land, are considerably overdeveloped, washing out the land features normally emphasized in standard processing procedures. The best exposure (which controls the ratio of density or contrast)[7] for detection of the chlorophyll a-containing phytoplankton in the water cannot be determined from just one set of photographs. However, overdevelopment of positive transparency and prints is essential, as can be seen by comparing figure 4 with figure 5. In figure 5 are presented essentially the same pictures as in figure 4, only the development time of the positive prints is normal, resulting in the definition of many land features. However, in these prints the water is essentially black; only the area where surface phytoplankton was reported and very high chlorophyll a concentrations measured, reflected sunlight.

Figure 6 includes a densitometer trace across print number 10 of figure 4, and its location is shown by the arrows on an identical print included on the right of this figure. The densitometer trace, which is the solid line, is presented relative to the density trace over the unexposed portion of the film (R) on the vertical scale and on the horizontal as distance from one edge of the river (X), in kilometers. In the figure the unexposed film is identified as A, the land area as B, and the water areas as C. As can be seen, the difference in R between B and A is large compared to the difference in R between C and A, and between C and the radiance from the chlorophyll a-containing phytoplankton in the majority of places. Therefore, since development time increases the difference in film density or contrast,[7] to enhance the phytoplankton radiance relative to the water, it is necessary to overdevelop the positive transparencies and prints - thus overexposing the highly radiant land area, but not the highly absorbing water area at the NIR wavelengths.

Also presented in figure 6, as the dashed curve, is the depth of the river bottom in meters, obtained from a marine map, plotted against distance across the river in kilometers. The purpose of this curve is to establish that the river between 0 and 1 kilometer, where there is a broad increase in R on the densitometer trace, labeled bottom radiance, is approximately 2 meters deep. The justification for concluding that the increased radiance in this area is due to sunlight penetration to, and reflected from, the bottom can be established by comparing the two simultaneous pictures on the right of figure 6. In the upper portion of the top photograph, just below the land, taken through the NIR filter that passes only red and infrared radiation, there is an increase in radiance as evident by the light area, while the same area of the bottom photograph, taken through the number 58 green filter that passes only green radiation, there is a decrease in radiance as evident by the area being dark in relation to its surrounding area. Therefore, the increase in radiance in the NIR photograph in this area cannot be due to chlorophyll a-containing phytoplankton, nor is it due to white light (foam), because the radiance is not increased in the same area of both the green and NIR photographs, and must be due to either red or infrared radiation. Dr. Lear has observed the bottom as being hard, red Maryland clay.

R obtained from densitometer traces of NIR photographs (Table 1) like the one seen in figure 6, over each area where the in situ chlorophyll a measurements were made, is plotted in figure 7, represented by the circles, against the measured chlorophyll a concentrations. The solid curve is faired through these data points. Also shown in figure 7 is the visibility depth (S), in meters, as seen by the eye, of a 30-cm white disk (Secchi disk) that was lowered into the water at each of the data stations. The dashed curve is a fairing through S, represented by the squares, that were also plotted against measured chlorophyll a concentrations. The dashed curve consists of two straight lines intersecting at the chlorophyll a concentration of 40 μg/ℓ which you can see fits the data reasonably well.

Observation of the faired values of R between the values of chlorophyll a concentrations of 4 and 34 μg/ℓ indicates that in the NIR R is not sensitive to chlorophyll a concentration over this range of concentrations. However, the faired values of S over this same range of chlorophyll a concentrations indicate that the light penetration into the water is decreasing with increasing chlorophyll a concentrations. Thus, the absorption of light with the increase in chlorophyll a concentrations over the range of 4 to 34 μg/ℓ, reduces the photic zone in the water, but does not affect the upwelling NIR radiation back through the surface of the water. Since the upwelling light back through the surface of the water is not influenced in this range of chlorophyll a concentrations, observations of the back-scattered light from scattering of the atmosphere and reflection off the surface of the water as a function of sun altitude angle[8,9] can be made, providing other contaminants in the water (such as suspended sediment) do not cause upwelling radiation through the surface of the water in the NIR wavelength.

The very low value of R in figure 7 over the range of 4 to 34 μg/ℓ of chlorophyll a concentrations suggests that suspended sediments are not significantly contributing to the upwelling light even though it is common knowledge that the Potomac River carries a heavy sediment load. This sediment load is confirmed by S of this figure which has a maximum penetration into the water of only 1.4 meters. However, it must be remembered that S was obtained with the human eye which responds best at the green wavelength of light (the attenution length of green light in distilled water approaches 20 meters[3]), and since the reflection from suspended sediment is a function of both quantity and particle size[10] it could be possible that the size of the sediment particles in the upper 2 meters of the river, for the river flow conditions on the day of this mission, are below the threshold value for upwelling of sunlight at the NIR wavelength. Therefore, the absence or the detection in the NIR of suspended sediment when chlorophyll a concentrations are below 40 μg/ℓ could provide information at one of the two wavelengths required for the measurement of suspended sediment.[10] The other wavelength would be around 523 nanometers where laboratory measurements[4] show the reflectance of chlorophyll a to be independent of concentrations between 1 and 30 μg/ℓ as it is in the NIR in this experiment.

Above chlorophyll a concentration of 34 μg/ℓ in figure 7, R increase and the S decrease, if any, is slight. Thus with chlorophyll a concentrations above 34 μg/ℓ, the situation is reversed, with the photic zone essentially constant and the upwelling light increasing. The transition point cannot be precisely determined from this experiment because of lack of data in the critical range of chlorophyll a concentrations, but it is defined as being between 34 and 51 μg/ℓ and is labeled "threshold for phytoplankton 'blooms'" on the figure.

The mechanism for the reversal of R and S cannot be determined from the data of this photographic mission, nor can the percentage of upwelled light indicated by the increase in R that would have been used for photosynthesis by the phytoplankton.

The values of R from a series of densitometer traces can be employed to map the chlorophyll a concentrations in a "bloom" area as seen in figure 8 for a 4-kilometer square of the river. As you can see in figure 8, chlorophyll a concentrations are very erratic, and would be impossible to describe or even average correctly with the limited ground truth data obtained during this photographic mission. However, it is possible to integrate the densitometer data that were used to construct figure 8 to determine the percent area coverage of various incremental ranges of concentration of chlorophyll a as shown in Table 3. Table 3 shows that only 23 percent of the water area in figure 8 contains chlorophyll a concentrations that are below the threshold concentration for producing phytoplankton "blooms." The largest percent of "bloom" area is between the chlorophyll a increment of 40 to 60 μg/ℓ with the "bloom" area of each chlorophyll a concentration increment progressively reduced with increasing chlorophyll a concentrations. Information of the type shown in Table 3 over a period of time would be strong input for monitoring the stress of a body of water from biodegradable pollution.[1]

CONCLUDING REMARKS

On October 2, 1972, a photographic flight, at 3 kilometers altitude, using Hasselblad cameras, was flown over the Potomac River "salt wedge area." During the same time in situ water measurements detected chlorophyll a concentrations that varied from 4 μg/ℓ to >3000 μg/ℓ.

From an analysis of photographs taken through the 89B near-infrared (NIR) Wratten optical filter and a selected picture taken through the number 58 Wratten green filter, along with corresponding ground truth data, the following conclusions can be made:

1. Overdevelopment of positive transparencies and prints from a negative that was overexposed in relation to the Kodak recommended normal exposure setting through an NIR filter greatly enhances the contrast between phytoplankton "blooms" and the water background.

2. The penetration of sunlight into water can be photographed through an 89B Wratten NIR filter to reveal bottom features as deep as 2 meters.

3. Using an NIR camera system, the threshold for phytoplankton "blooms" is between the chlorophyll a concentrations of 34 and 51 μg/ℓ.

4. The upwelling of NIR light through the surface of the water is independent of chlorophyll a concentrations below a value of 34 μg/ℓ.

5. The penetration of sunlight into the water as determined by the eye from lowering of a 30-cm white disk (Secchi disk) into the water decreased with increasing concentrations of chlorophyll a below the concentrations of 34 to 51 μg/ℓ, and remained nearly constant with further increase in chlorophyll a concentrations.

6. Detection of upwelling light in the NIR coupled with detection near 523 nanometers has a potential for measurement of suspended sediment when chlorophyll a concentrations are below 34 μg/ℓ.

7. Synoptic pictures in conjunction with limited ground truth data makes detection and mapping of chlorophyll a-containing phytoplankton "blooms" possible over large areas of water - thus providing a strong input for monitoring the stress in a body of water from biodegradable pollutants.

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Table 1. EPA,[1] Mid-Potomac Estuary Phytoplankton Surveillance Data, Surface Samples, October 2, 1972

Sta. No.	Location[2]	Time[3]	Tide	Cond. µmhos	Salinity °/oo	Temp. °C	DO mg/ℓ	Secchi[4] Disc-m.	Chloro- phyll a µgm/ℓ	Wind dir.	Wind vel., mph	See state	R[5]
1	N 32	1415	Slack	12.1	7.5	21.0	5.8	1.44	007.5	N	0-2	Calm	0.94
2	Below Br. West Side	1408	Slack	10.5	6.6	20.5	6.0	1.52	930.0	N	0-2	Calm	.74
3	Buoy CN	1403	Slack	10.5	6.4	21.4	6.4	1.80	34.5	N	3-6	Ripples	.87
4	Nun 25P Popes Cr.	1355	F	10.3	6.7	21.4	---	1.18	16.5	N	3-6	Ripples	.78
5	C 3	1346	F	9.8	6.0	21.3	6.0	.67	10.5	N	3-6	Ripples	.90
6	C 7	1337	F	8.6	5.4	21.4	---	1.23	4.0	N	3-6	Ripples	.77
7	C 9	1328	F	8.0	4.8	21.2	6.5	.93	10.0	N	3-6	Ripples	.78
8	N10	1320	F	7.1	4.4	21.2	6.9	.95	9.0	N	3-6	Ripples	.80
9	N16	1306	F	5.7	3.4	21.7	7.0	.77	332.0	N	3-6	Ripples	4.58
10	C19	1253	F	4.2	2.7	20.9	7.0	.82	6.0	S	2-5	Ripples	.94

[1] EPA, Annapolis Science Center, Annapolis, Maryland 21401.
[2] Coast and Geodetics Survey Navigation Map #559.
[3] Eastern daylight time.
[4] The visibility depth of a 30-cm-diameter white disk.
[5] Relative reflectance, as determined by difference between light transmittance of densitometer traces over the in situ data point location on the film relative to traces over the unexposed portion of the film.

Table 1. EPA,[1] Mid-Potomac Estuary Phytoplankton Surveillance Data, Surface Samples, October 2, 1972 - Concluded

Sta. No.	Location[2]	Time[3]	Tide	Cond. µmhos	Salinity °/oo	Temp. °C	DO mg/ℓ	Secchi[4] Dis-m.	Chlorophyll a µgm/ℓ	Wind dir.	Wind vel., mph	Sea state	R[5]
11	Buoy 22	1242	F	3.20	2.1	20.7	7.5	0.82	57	S	2-5	Ripples	----
12	Off	1230	F	2.75	1.7	21.3	7.6	.46	>3128	S	2-5	Ripples	18.40
	Potomac Cr.												
13	N26	1222	F	2.45	1.5	20.5	7.5	.59	783	S	2-5	Ripples	6.24
14	Off	1210	F	1.85	1.2	21.3	7.5	.72	1192	S	2-5	Ripples	5.80
	Acquia Cr.												
15	N30	1201	F	1.80	1.0	20.2	7.5	.62	79	S	2-5	Ripples	2.38
16	N34	1154	F	1.25	.85	21.0	7.4	.67	328	S	2-5	Ripples	4.30
17	Off Va.	1146	F	1.00	.6	21.1	7.4	.64	51	S	2-5	Ripples	1.56
	Shore												
18	N40	1137	F	.75	.5	20.8	7.1	.72	559	S	2-5	Ripples	6.19
	Mallow's Bay												
19	C41	1130	F	.40	.2	20.7	6.7	.72	76	S	2-5	Ripples	2.80
20	Buoy 44	1120	F	.25	.1	20.65	7.3	.59	274	S	2-5	Ripples	4.52

[1] EPA, Annapolis Science Center, Annapolis, Maryland 21401.

[2] Coast and Geodetics Survey Navigation Map #559.

[3] Eastern daylight time.

[4] The visibility depth of a 30-cm-diameter white disk.

[5] Relative film transmittance, as determined by difference between light transmittance of densitometer traces over the insitu data point location on the film relative to traces over the unexposed portion of the film.

Table 2. Sensor Complement and Camera Settings

	Camera	Focal length (mm)	Filter[1]	Film format (mm)	Film type[2]	AEI[3]	Speed[4] (sec)	f-[4] number
1.	Hasselblad	40	58 (green)	70	2402 Black & White	6	1/250	5.6
2.	Hasselblad	40	12 (yellow)	70	2402 Black & White	40	1/250	11
3.	Hasselblad	40	89B (NIR)	70	2424 Black & White NIR	28	1/250	8
4.	Hasselblad	40	HF-5 (haze)	70	SO-397 Color	12	1/250	5.6

[1] Kodak Wratten filter number.

[2] Kodak film number.

[3] Kodak recommended aerial exposure index.

[4] Actual exposure.

Table 3. Area Distribution of Chlorophyll a Concentrations From Integration of Data for Figure 8

Chlorophyll a concentrations, μg/ℓ	Area covered, percent
<40	23
40 to 60	36
60 to 100	18
100 to 175	6
175 to 300	5
300 to 460	3
>1000	6

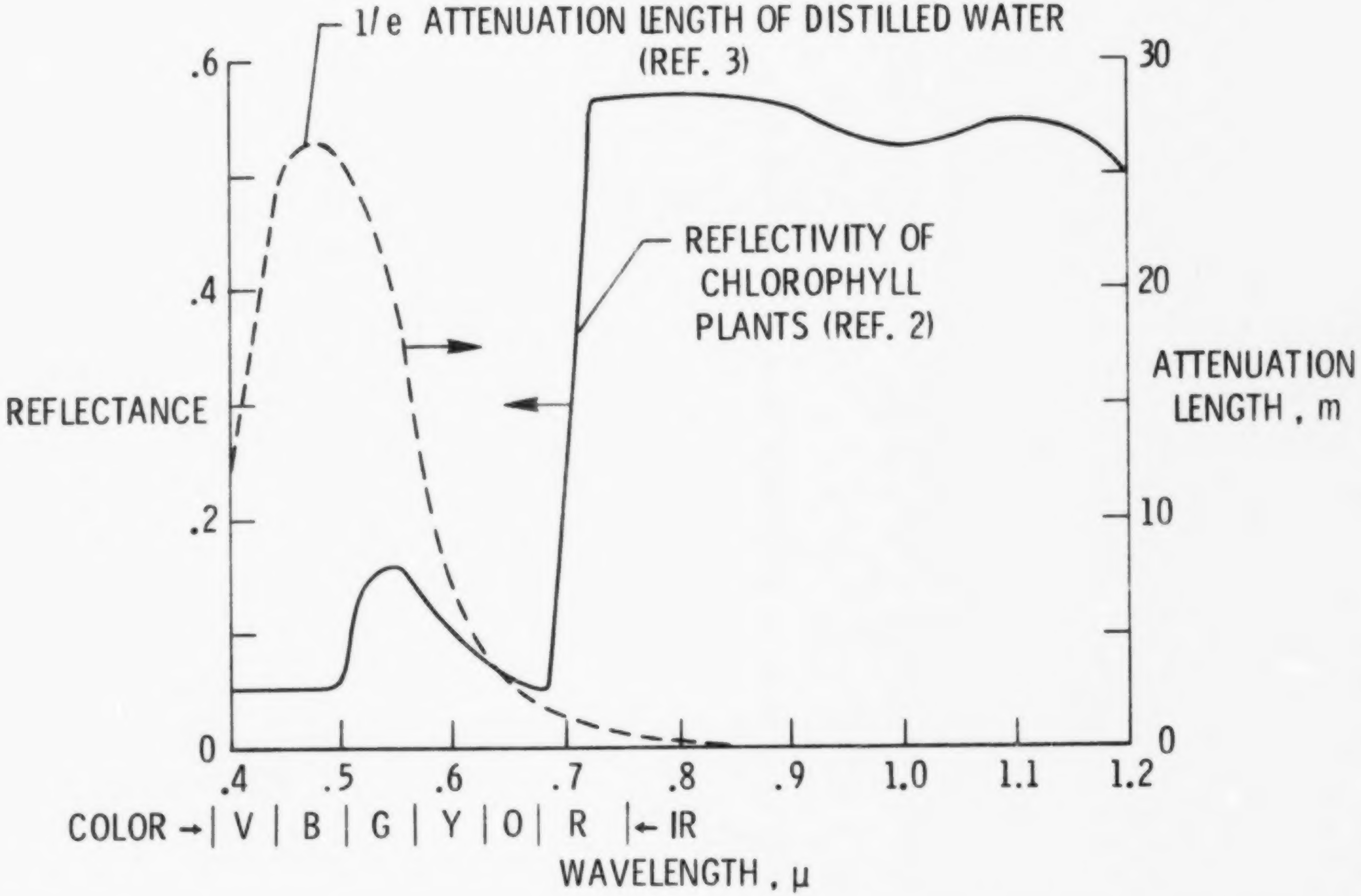

Figure 1. Comparison of the reflectance of chlorophyll-containing plants with the attenuation length of sunlight in distilled water.

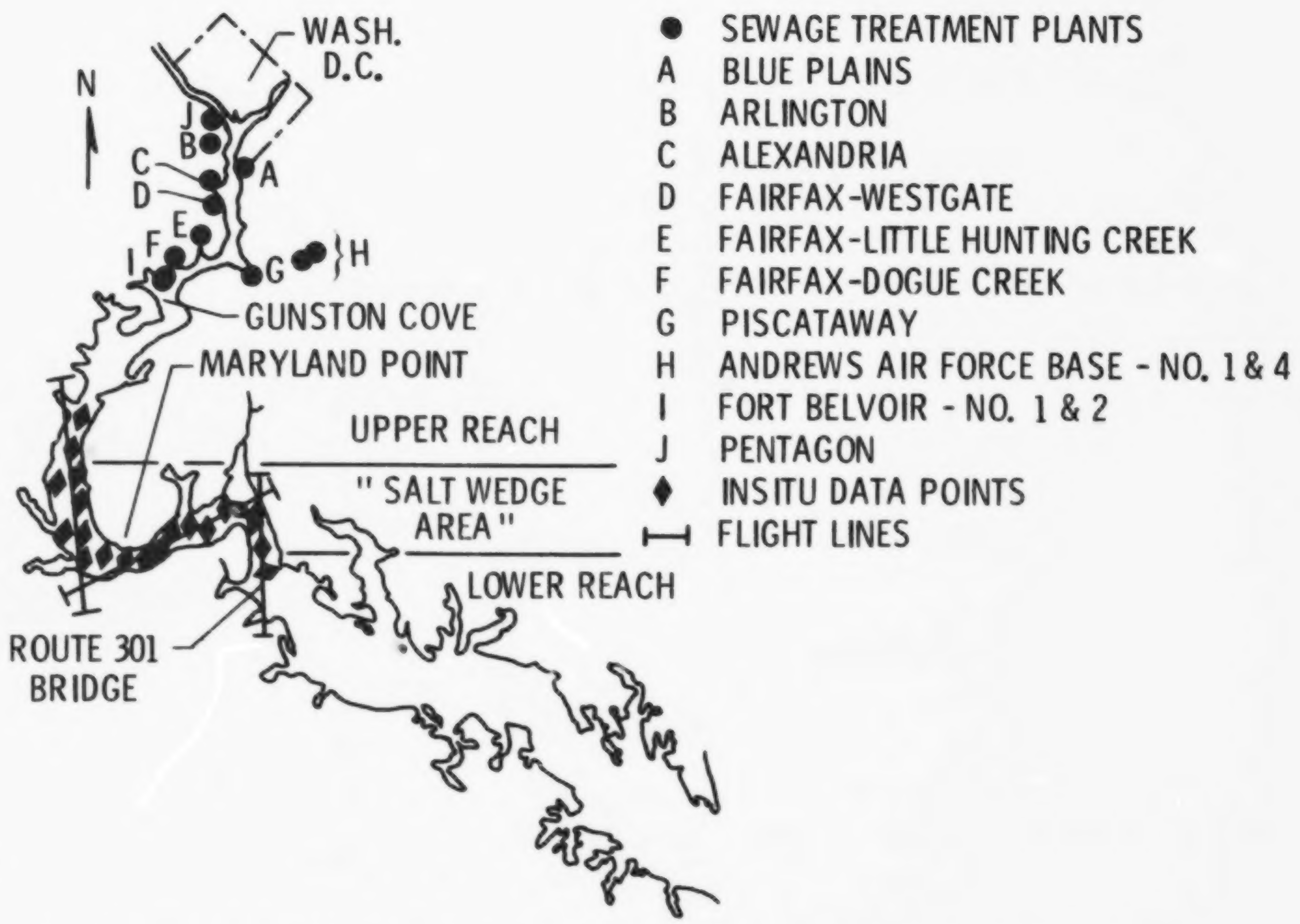

Figure 2. Normal location of Potomac River "Salt Wedge Area" relative to location of in situ data points, flight lines, and sanitation plants.

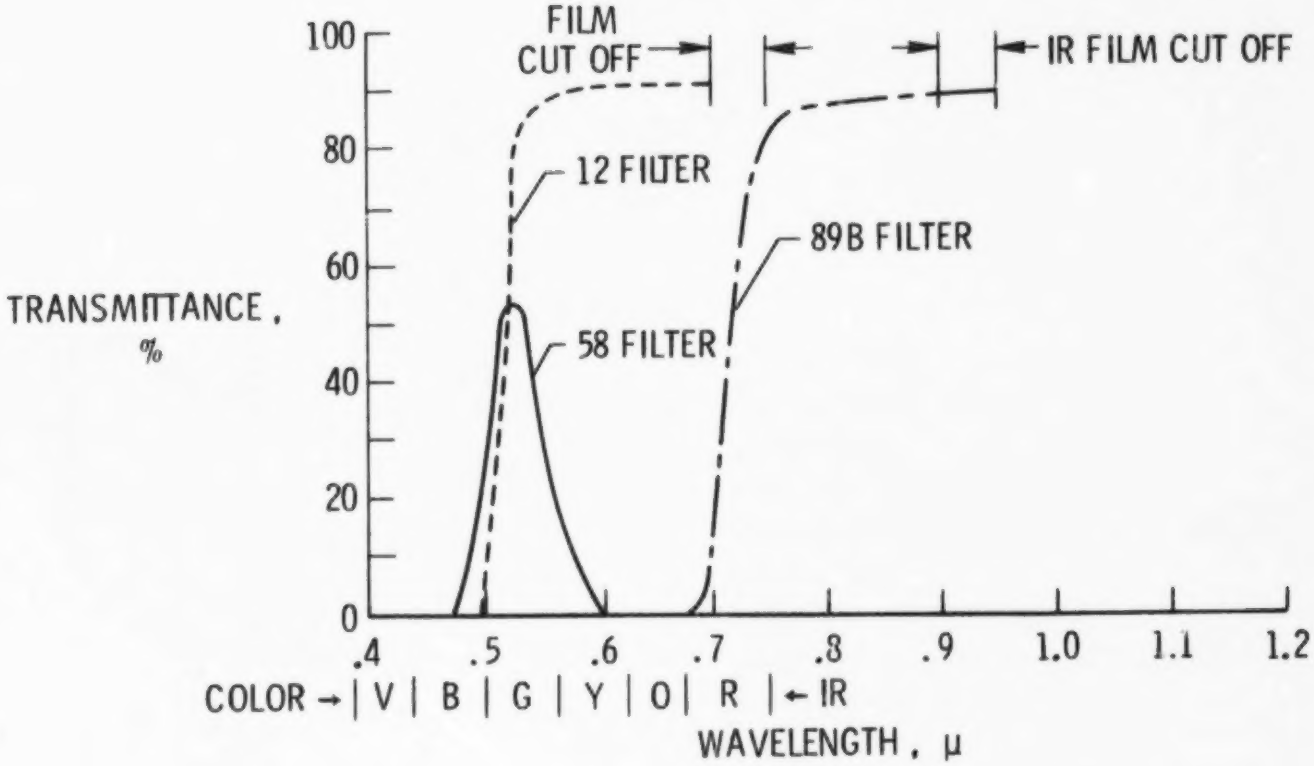

Figure 3. Filter selection and film cutoff for detection of phytoplankton.

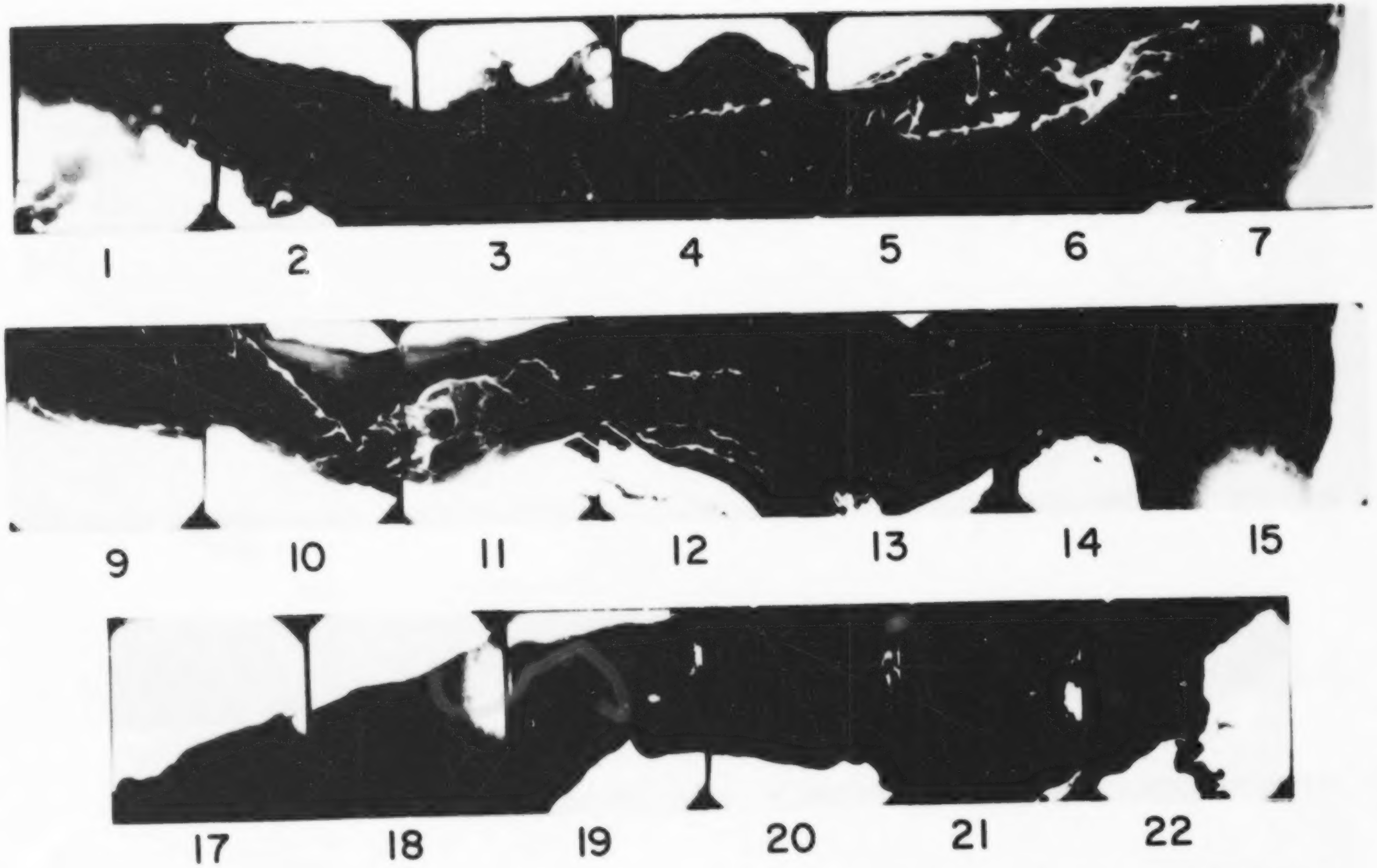

Figure 4. A series of photographic prints along the Potomac River from Possum Point to Bluff Point, taken through the number 89B near-infrared Wratten optical filter, from 3 kilometers altitude.

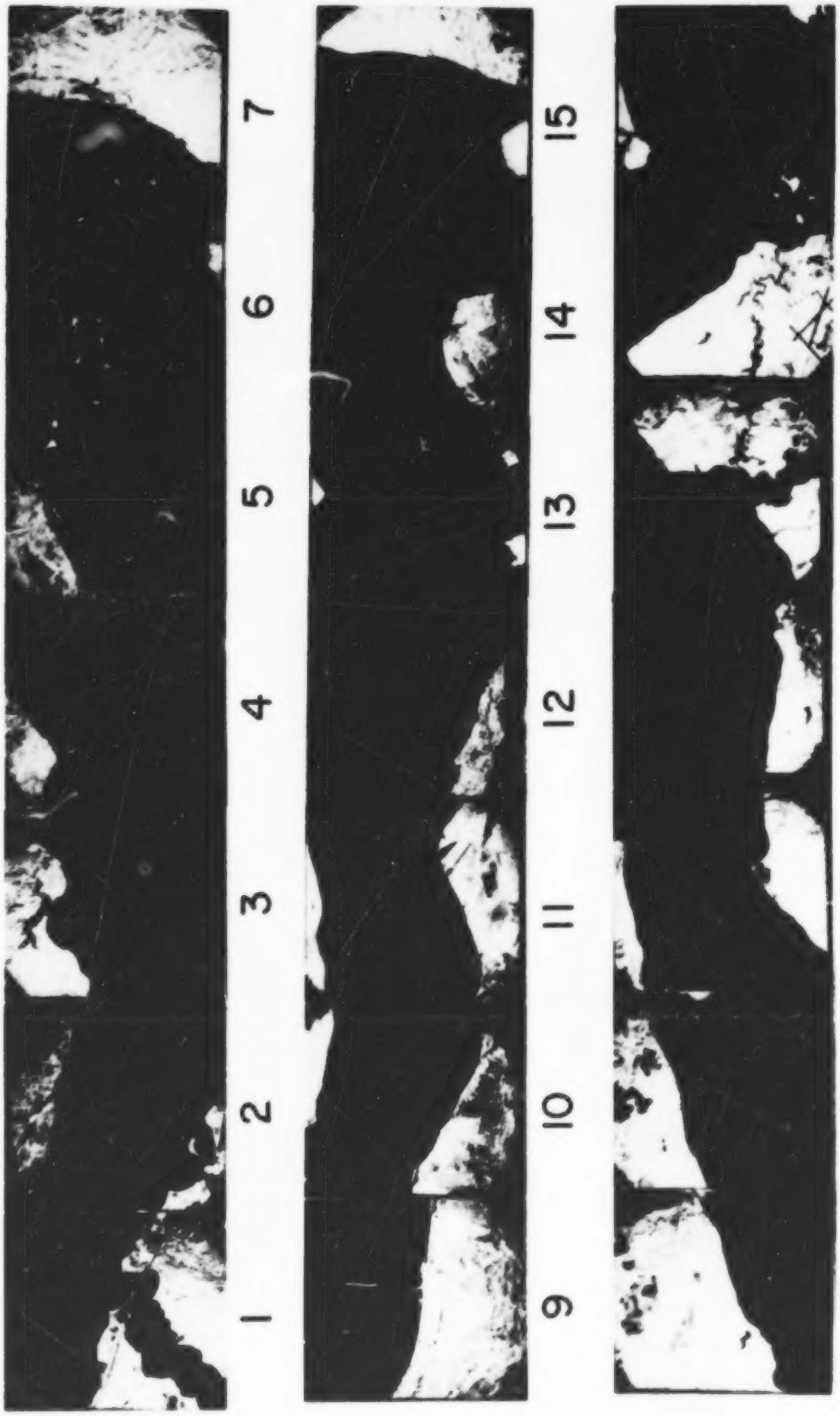

Figure 5. Essentially the same series of pictures as in figure 4 only the development time for the positive prints is reduced in order to define the land features.

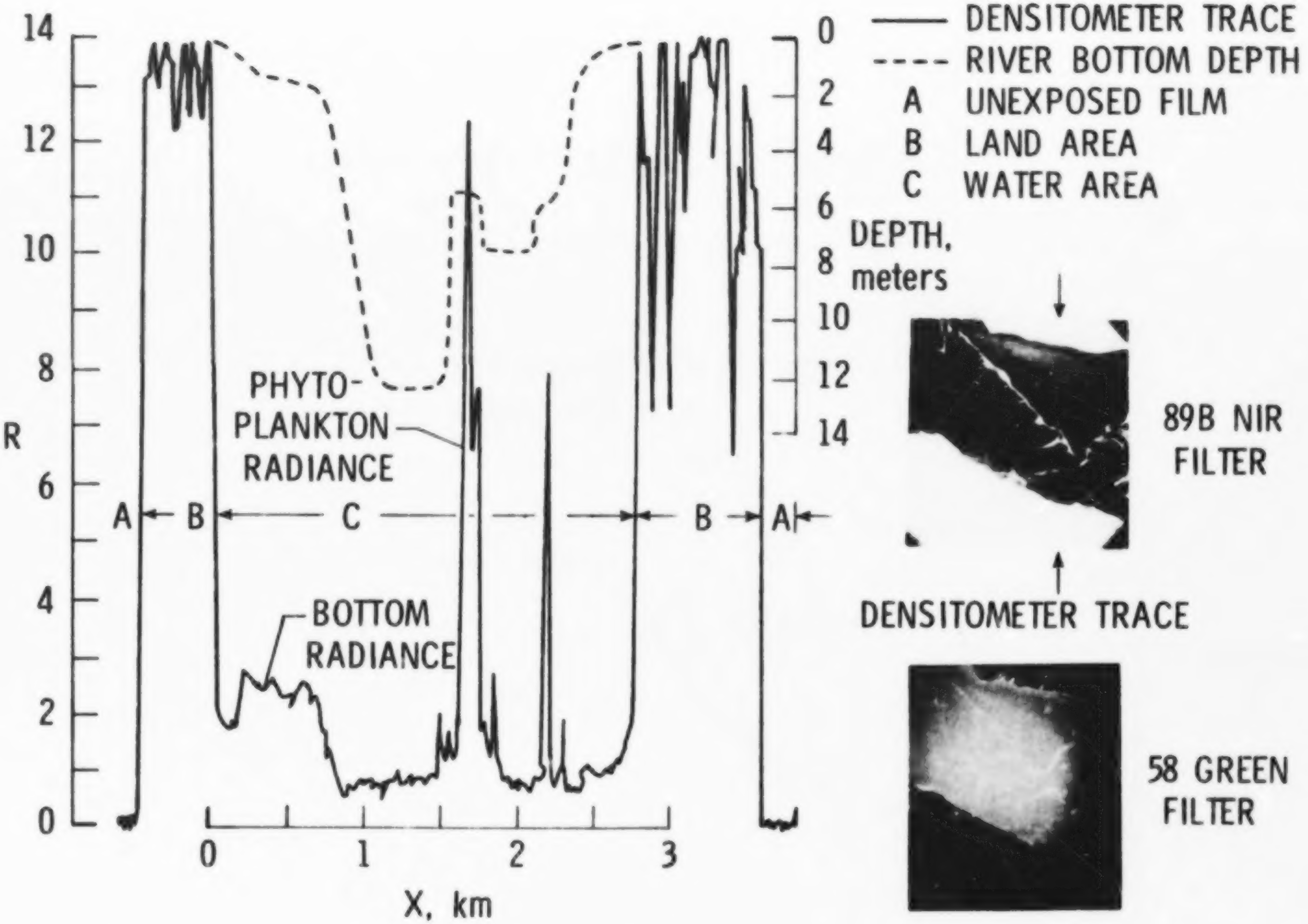

Figure 6. Densitometer trace across the number 10 near-infrared (NIR) photograph of figure 4, showing radiance of land, water, phytoplankton, and the river bottom, relative to the unexposed film, in the form of relative film transmittance, R, and river bottom depth versus distance across the river.

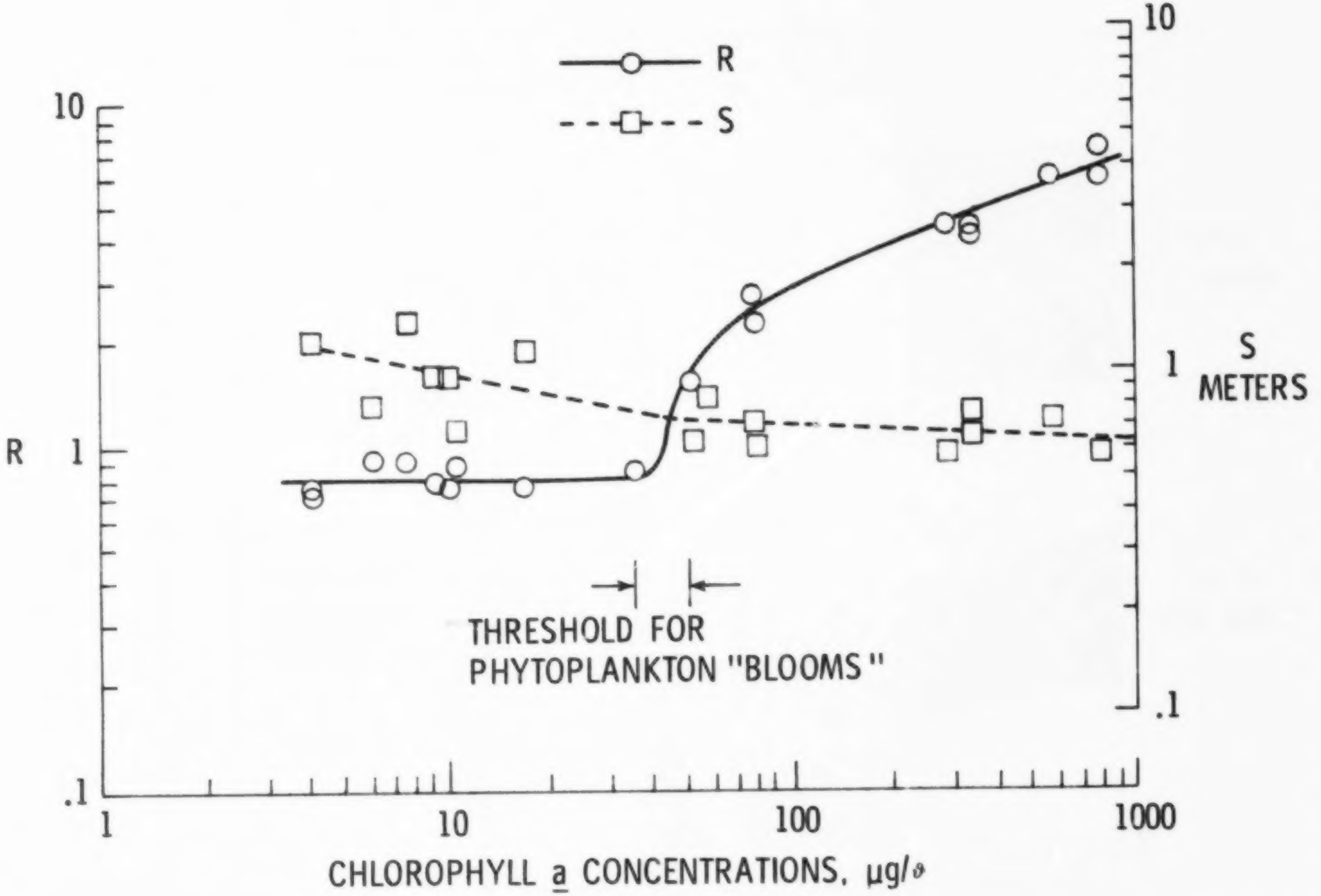

Figure 7. Relative film transmittance, R, from densitometer traces and 30-cm Secchi disk depth, S, versus measured chlorophyll a concentrations.

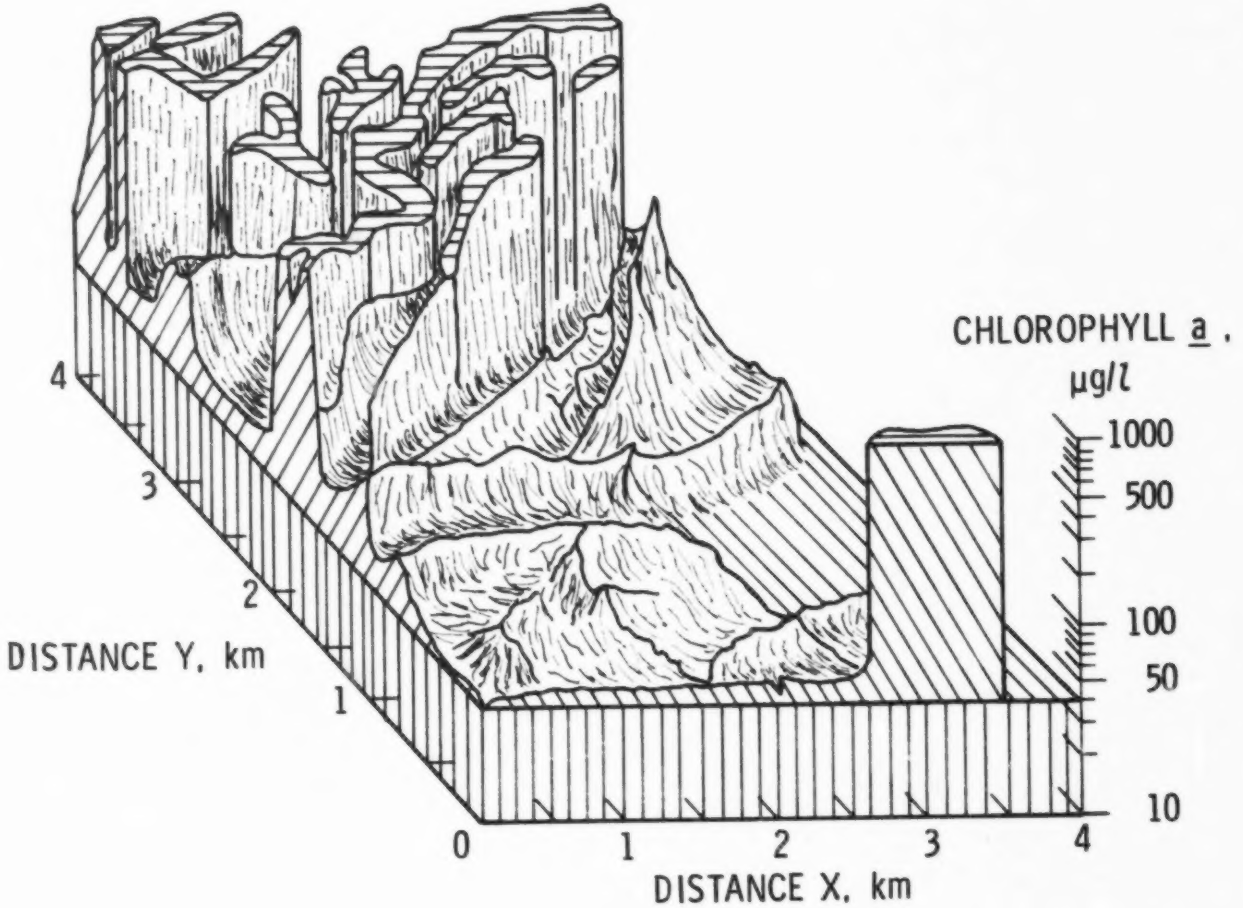

Figure 8. Distribution of chlorophyll a concentrations over 16 square kilometers of the Potomac River obtained from densitometer traces of picture 6 in figure 4.

SESSION III

AIR QUALITY SENSOR DEVELOPMENTS

CHAIRMAN

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ST. LOUIS
REGIONAL AIR MONITORING SYSTEM

JAMES A. REAGAN

Presented at the

Second Environmental Quality Sensor Conference

October 10-11, 1973

NATIONAL ENVIRONMENTAL RESEARCH CENTER
LAS VEGAS, NEVADA

The St. Louis Regional Air Monitoring System

James A. Reagan

ABSTRACT

The Regional Air Monitoring System (RAMS) consists of 25 stations observing gaseous, particulate, meteorological, and radiation parameters. Distribution of the stations is on four concentric circles, centered on the arch, and at distances of 4, 9, 20, and 40 kilometers. The system is designed for a 90% data capture, excluding scheduled calibration. Scheduled maintenance was designed in conjunction with remote calibration capabilities to reduce operational manpower requirements.

Parameters monitored at one or more stations include: sulfur dioxide, hydrogen sulfide, total sulfur, carbon monoxide, total hydrocarbons, methane, nitrogen dioxide, nitric oxide, ozone, visibility, wind speed, wind directions, temperature, relative humidity, pressure, temperature differential, solar radiation, three component wind speed, and particulate loading. Each station has independent operational capability, including in situ recorders. Stations are linked via a telephonic communication network to a data center. Routine monitoring of the data stream is made to flag observational or system monitoring anomalies.

The system is designed to be a research tool, implying a high quality of data, yet fabricated and operated at minimal expense. Technology spinoff will include system design specifications, performance specifications, operation, and troubleshooting

manuals for system components. Data from the network will be available to requestors through a convenient distribution channel.

INTRODUCTION

The Regional Air Pollution Study or RAPS will develop mathematical simulation models of atmospheric processes affecting the transport and concentration of air pollutants. Extensive source and receptor data will be collected. Additional coordinated experiments to elucidate interim species, reaction rates, and energy balances will be performed.[1]

Any of these models may be represented by the relation of the change in time with the change in space equals the losses and additions from reactions and sources and due to diffusion.

$$\frac{\partial \bar{c}}{\partial t} + \frac{\partial}{\partial x} (u\bar{c}) = \bar{D} \frac{\partial^2 \bar{c}}{\partial \bar{x}^2} + \bar{R} (\bar{c},T) + \bar{S} (x,t)$$

This vector differential has many submodels which require development.

Figure 1, displaying the schematic of the model, is a diagram of the overall system. Sulfur and particulates primarily from stationary sources, along with nitric oxide and hydrocarbons from mobile sources, are transported through the atmosphere. In route they undergo a series of complex reactions with one another resulting in new species formation and alteration of existing ones. Ambient air quality is translated into effects on the people and the environment.

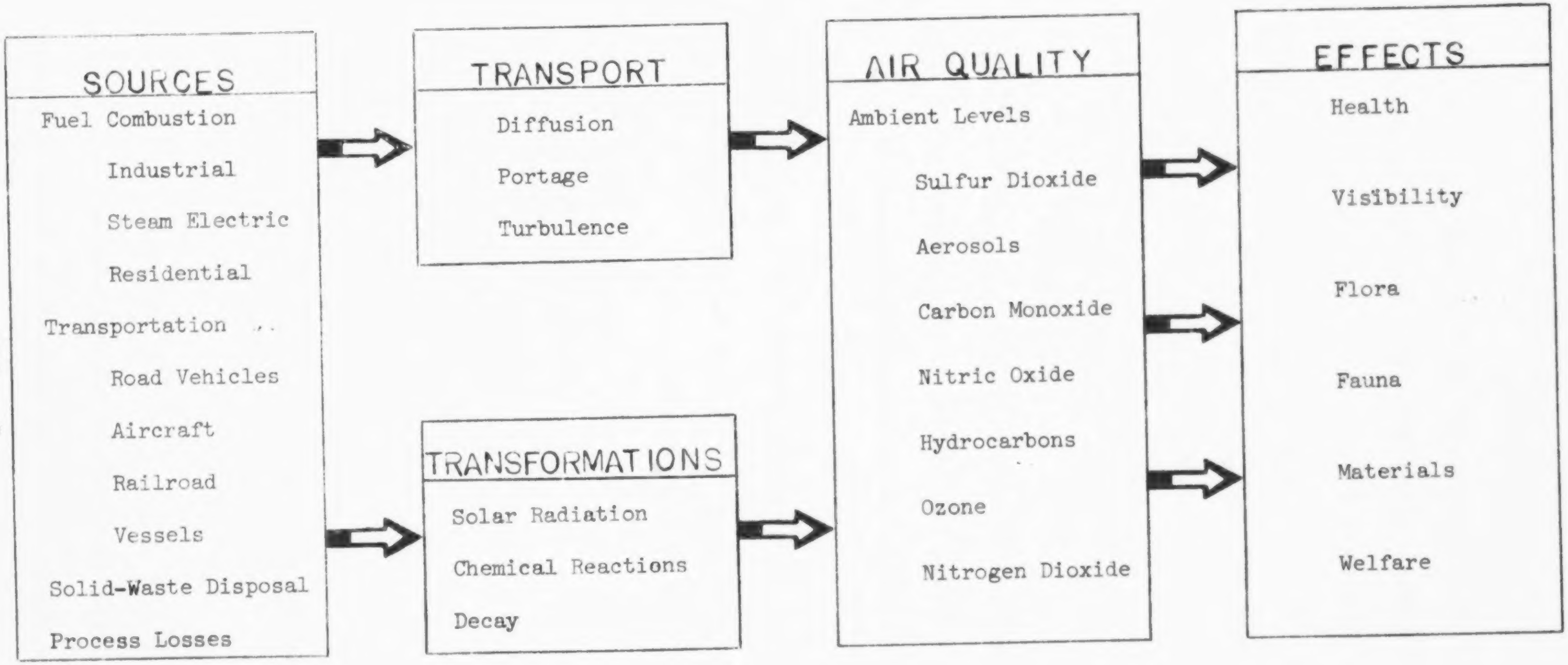

SOURCES
Fuel Combustion
Industrial
Steam Electric
Residential
Transportation
Road Vehicles
Aircraft
Railroad
Vessels
Solid-Waste Disposal
Process Losses
TRANSPORT
Diffusion
Portage
Turbulence
TRANSFORMATIONS
Solar Radiation
Chemical Reactions
Decay
AIR QUALITY
Ambient Levels
Sulfur Dioxide
Aerosols
Carbon Monoxide
Nitric Oxide
Hydrocarbons
Ozone
Nitrogen Dioxide
EFFECTS
Health
Visibility
Flora
Fauna
Materials
Welfare

Figure 1

The RAMS measures portions of each box except Sources. Meteorological measurements give data for the characteristic transport. Incident solar energy of the right wavelength drives some of the critical chemical transformations. All of the pollutants are monitored by appropriate air quality sensors. Resultant effects on visibility are also measured. This system then is designed to provide many direct measurements on the model parameters.

GENERAL SYSTEM

RAMS consists of 25 stations situated throughout the St. Louis area. Each station has a full compliment of basic air quality and meteorological monitoring equipment. They are linked together via a telecommunications network, and all data are sent to the central data acquisition system on a one minute polling frequency. Several stations have special sampling equipment which is placed because of site or area considerations.

The system is designed to achieve a 90 percent data capture rate. Scheduled maintenance is excluded from this. We felt that the equipment is not state-of-the-art, albeit close to that. Therefore, the system was awarded on a performance contract basis as long as certain standards of technical excellence were met or exceeded. Currently, the schedule calls for the first station to be delivered in late January 1974, with the remainder following at a rate of one per week.

SITING CRITERIA

Dr. Francis Pooler, in his paper on the "Network Requirements for the St. Louis Regional Air Pollution Study,"[2] discusses the number and position of stations with the guidelines of the study objectives, as follows:

1. Extensive spatial coverage is necessary for including the entire metropolitan area.

2. For large networks the marginal increase in knowledge with the addition of each station declines after the nth station.

3. Simultaneous measurements should be made at all sites for a long enough interval of time to include all the varying weather regimes.

4. Station costs become fixed after about ten stations. Most manufacturer discounts do not decrease after the 10th item.

5. The same measurements should be made at all sites.

6. Minimize labor costs, even if reasonable increased capital costs are initially incurred.

7. Colocate meteorological measurements with air quality measurements for convenience.

We settled on a subjective number of 25 stations as being adequate to supply our needs. This was reached by considering four concentric circles of six stations each around a central station. This has been modified as shown on the map.

To arrive at the final network layout, several factors were considered:

1. At least one station should be in the upwind sector, regardless of the wind direction.

2. Comparison of upwind-downwind measurements is desireable; therefore, each upwind site should have a downwind counterpart.

3. Place sites so that the station density is roughly proportional to pollutant gradient.

4. Incorporate existing monitoring efforts as much as is feasible.

The first criteria can be met by placing four rural sites at approximately 90 degrees azimuth spacing. Existing data show that the gradient slackens off out to 10 kilometers from the Arch, with most concentrations occuring in that area. The St. Louis City/County network and the Illinois EPA network constitute most of the existing surveillance system. Therefore, the rings were set at distances of 4, 9, 20, and 40 kilometers from the central station. Actual station location is within less than a kilometer for the center city stations, increasing to a 5-kilometer area on the outer ring. Density was also increased in the third ring to eight stations since most of this ring is in the heavy surburban area. The four outer stations are designed to monitor background levels.

Several specific criteria must be followed as much as possible.

1. The site should be representative of a reasonably large area.

2. The site should be 1 kilometer or more from a major traffic artery.

3. Site should not be in the lee of a building.

4. There should be no significant obstruction to the air flow higher than one-tenth the distance to the obstruction from the point of measurement.

5. Terrain should be representative of the surrounding area that is not in a depression.

6. Power and communications should be available, for they can be very expensive to bring any great distance.

Locations for sites were defined to allow the chance of finding inexpensive, acceptable sites. An absolute coordinate location is impossible to achieve in an urban area.

STATIONS

Each station is a 10-by-16-foot shelter mounted on concrete piers. A free standing 10 or 30 meter tower is adjacent to the station on the northerly side. The shelter is of prefab construction with white walls and a flat roof with steel mesh covering to allow roof access and utilization. A four-ton cooling system with good internal air circulation is provided to maintain a constant temperature of $72^\circ \pm 3^\circ$. Instrument heat is sufficient to require cooling to temperatures near the freezing point of water. Dual exits are provided for quick exit as well as an automatic heat sensing and Freon fire extinguishing system. Air pumps are mounted in a sound-proofed box which doubles on top as bench space. Gas cylinders are placed in a fire-proofed compartment with forced air draft to prevent the build-up of explosive gas concentrations. Hydrogen is provided to the instruments by means of a catalytic separator in lieu of pressure bottles.

The air quality sensors have been provided with zero and span gas systems capable of remote actuation. This is an example of a capital equipment expenditure which should pay for itself within one year by reduced personnel costs. Critical air flows, power levels, range settings, and calibration status are monitored to assure proper component performance.

Air quality instruments were selected to:

1. Detect levels below normal ambient level minima.
2. Have noise generally less than one percent of full scale values.
3. Have zero and span drift no worse than one percent a day or 3 percent in three days.

4. Operate without failure for more than a week.

These specifications are general, and each instrument has a specific set applicable to it.

Instruments selected are not on board, so they must still be considered tentative. They include good analyzers, performance and price considered, but are not necessarily the only instruments having good performance, low price, or both. The choices certainly cannot constitute an Agency endorsement, since we have not had an evaluation of the application of Finagle's laws to this system.

Each station will have an ozone monitor based on the chemiluminescent method. The probable instrument is the Monitor Labs 8410.

Each station will have a NO_x box capable of direct NO and NO_x determination and NO_2 inference. The probable instrument is the Monitor Labs 8440.

Each station will have a total hydrocarbon, methane, carbon monoxide monitor based on chromatographic separation. The probable instrument is the Beckman 6800.

Twelve stations will have a total sulfur monitor based upon flame photometric detection. The other 13 stations will have a sulfur gas chromatograph capable of total sulfur, hydrogen sulfide, and sulfur dioxide. Most station locations should have only sulfur dioxide impinging upon them. This is due to the primarily local source nature of any other sulfur gas. Since the total sulfur analyzer is cheaper by half than the chromatograph, as well as more dependable, we split the stations in half for these measurements. Chromatographic analyzers will be placed where other sulfur gases maybe expected or are known to be present. The probable total sulfur analyzer will be the Meloy SA 185, and the Chromatograph, the Tracor 270 HA.

Each station will have a nephelometer for visibility and fine particulate determination. This will be the MRI 1550, the only one on the market.

Each station will have two gas bag samplers for the determination of hydrocarbon concentrations by laboratory chromatographs. If the bag material is suitable, they may be used for the collection and analysis of tracer compounds such as sulfur hexaflouride and freon 11.

All meteorological instruments will likely be provided by MRI with one exception.

Each station will have wind speed, direction, and ambient temperature.

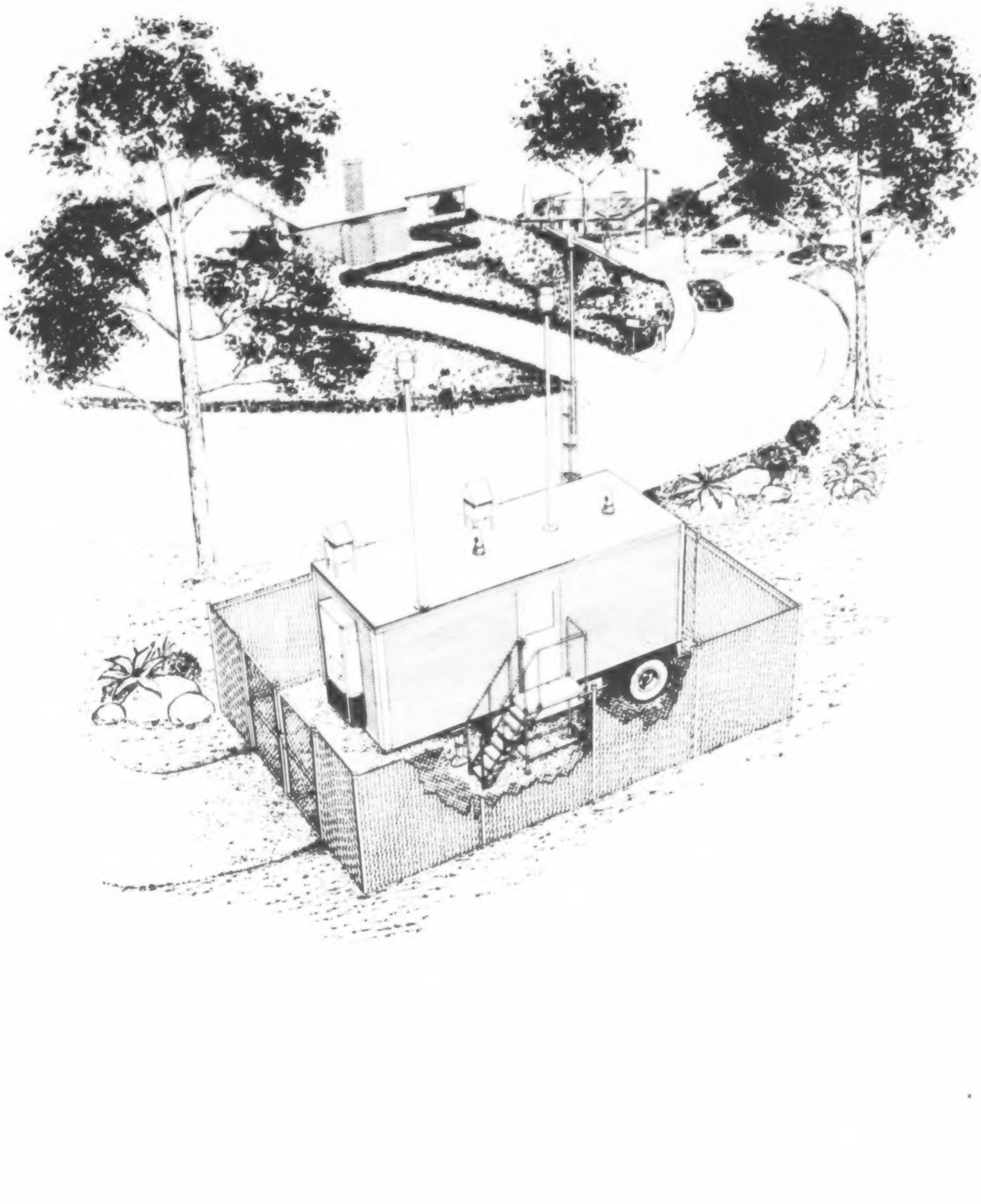
Twelve stations will have a temperature differential between ground level and 30 meters.

Barometric pressure will be measured at seven stations, essentially the outer perimeter and one diameter through the system.

Dew point will be measured at each location, probably with the Cambridge 880.

All meteorological instruments were ordered with the provision that they meet standard catalog specifications. The determination of relative humidity or dew point is considered to be especially important since this heavily influences aerosol formation.

Solar radiation measurements will be made at up to six stations to determine the incident solar output. All equipment will probably



be provided by Eppley and have common batch optical glass filters.

Measurements made include total incident radiation, total 300-395 nanometer radiation, and total 300-695 nanometer radiation using pyronometers. Pyrheliometers with filter wheels consisting of filters having no cutoff, 395 nm cutoff, 475, 530, 570, 630, 695, and 780 nm cutoffs. Pyrogeometers measuring 3-50 μm will also be used.

Spare parts for the instruments were established as spare instruments in the amount of 10 percent for all instruments except the chromatographs, for which 20 percent will be ordered.

The outputs from each sensor are converted by an Xincom A/D converter to digital input to a PDP-8/M computer with 16K core, Pertec magnetic tape drive 9 channel, 800 bpi density and ASR-33 teletype. Addition of new equipment is easy because of the extra control and data sampling capabilities of the data acquisition system. Data is continuously recorded in situ, allowing the telecommunications link to be lost with no loss of data except in real time.

CENTRAL FACILITY

A PDP-11/40 computer with 32K core, three tape drives, three 1.2 megaword dishes, console, line printer, card reader, graphics printer/plotter and CRT is the base of the data acquisition system. A PDP-11/05 front end processor handles station telecommunications while the foreground of the 11/40 handles peripheral devices and the Disk Operating System is kept in background.

Each station/instrument is polled each minute, and a one-minute average is transmitted to the central computer. Each station samples once each half second and stores the sum until converted and transmitted. Raw voltages are written to magnetic tape, which is subsequently processed to produce a tape with validated one-minute values. Hourly averages are formed in the computer and kept for up to a month on the random access storage.

The primary purpose of the central computer is to handle large volumes of data from the network, as well as other sources, such as special mobile samplers or aircraft. It can be used to validate and get a quick look at data, but it is not for the testing of models or any large scale correlation work. It is intended that the total data base will be accessible by the Univac 1110 system which will be at the Research Triangle Park.

SUMMARY

RAMS is a portion of the overall Regional Air Pollution Study. It is designed to be a research tool and not an enforcement monitoring network. The contractor selected for fabrication and operation is the Rockwell International Science Center of Thousand Oaks, California. Anyone desiring detailed descriptions and specifications should contact me at the EPA office in St. Louis.

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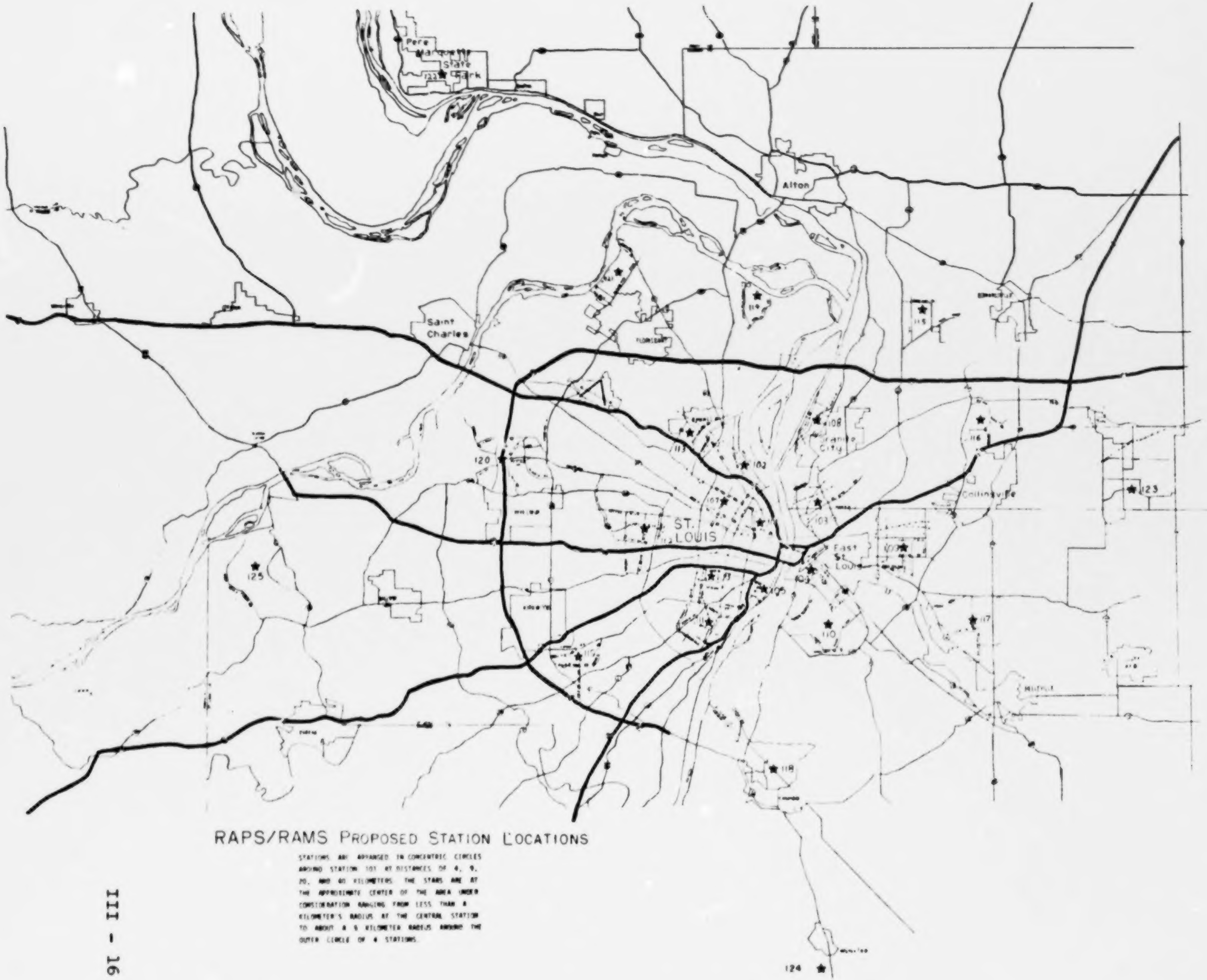

RAPS/RAMS PROPOSED STATION LOCATIONS

STATIONS ARE ARRANGED IN CONCENTRIC CIRCLES AROUND STATION 101 AT DISTANCES OF 4, 9, 20, AND 40 KILOMETERS. THE STARS ARE AT THE APPROXIMATE CENTER OF THE AREA UNDER CONSIDERATION RANGING FROM LESS THAN A KILOMETER'S RADIUS AT THE CENTRAL STATION TO ABOUT A 5 KILOMETER RADIUS AROUND THE OUTER CIRCLE OF 4 STATIONS.

LONG PATH OPTICAL MEASUREMENT OF
ATMOSPHERIC POLLUTANTS

Material prepared for discussion with EPA Regional
S & A Representatives, NERC-LV, October 10-11, 1973

By

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Air Quality Measurement Methods Branch
Chemistry & Physics Laboratory
NERC-RTP

At the time when this symposium was first being organized early this summer, John Koutsandreas asked me to participate by describing that work of my branch related to remote sensing of pollutants. I promptly breathed a sigh of relief and explained to John that my branch, being totally concerned with the measurement of pollutants in ambient air, has no work in progress aimed at remote sensors. I went on to explain that we have given considerable thought to the concept and have concluded that, since there exist no physical or legal restraints upon our access to the air around us, there is no demonstrable need for sensing its pollutant content remotely.

It turned out, however, that my sigh of relief was premature. It seems that the symposium organizers were aware of certain of our ongoing work and felt that it was within their sphere of interest. Naturally, I felt complimented by their interest, and willingly joined in a semantic discussion that soon led to a redefinition of remote or non-contact sensors. They are, for the purposes of this paper, those devices that accomplish the measurement of an atmospheric pollutant without physically transferring a sample of the air to an observation chamber within the instrument. In order to clarify this definition and thus avoid later confusion, let us look at two illustrative examples. An instrument that measures a pollutant by observing its spectral properties within a closed cell into which an air sample is pumped is obviously in contact with its sample. A second instrument that performs the identical function by observing the spectral properties of the pollutant along the path of a light beam projected from the instrument to an external reflector and thence back to the instrument is - by this definition - non-contact, although a purist might argue that the reflected external beam effectively stretches the instrument out and wraps it around the observed sample. I repeat that, for the purposes of this paper, the latter is defined as a non-contact operation.

The program of the Air Quality Measurement Methods Branch includes a single segment comprising non-contact measurements as I have just defined that term. The remainder of my presentation will consist of descriptions of the several tasks presently operating within that segment.

Presently, there are three active contracts within the area of long path optical measurement of ambient air pollutants. As all three are based on the same basic principle a single description of that principle will apply to all three and thereby save both your time and mine.

Monochromatic light having a wavelength corresponding to a principal absorbance maximum of the pollutant to be measured is projected outwardly from a source to a retroreflector, which returns the beam to its origin. There sensitive detectors read the intensities of the transmitted and received beams. Electronic logic devices compare the two light intensity values and display a signal representing the attenuation of light of the selected wavelength as the beam traversed the path source-reflector-detector.

In the simplest case the light attenuation whose measurement we have just described serves as a direct measure of the concentration of the pollutant of interest. But Nature is seldom simple, so in any real-life situation we will observe an attenuation that is the sum of that caused by the pollutant, plus that caused by other gases present - e.g., CO_2, water -, plus a further loss caused by turbulence of the air in the optical path. If we are to obtain an accurate measure of a pollutant we must find ways of eliminating the extraneous effects.

Potentially interfering contributions to light attenuation, if they are wavelength-independent, can be effectively eliminated by reading the difference in attenuation between two wavelengths, one being at a peak, the other at a valley, in the absorbance spectrum of the pollutant of interest. This strategy is capable of almost completely eliminating the turbulence effect, provided the two wavelengths are observed over a period (milliseconds) less than the time required for a significant change to be induced by turbulence. Its capability for eliminating interferences due to other absorbing gases is less, to the degree that the spectra of such gases possess structure at or near the wavelength of observation. This capability can usually be extended, however, by observing at three, four or more wavelengths in a manner such that some algebraic combination - say A - B + C - D, for a simple example - is dependent on pollutant concentration but independent (or relatively so) of the interferent.

The light sources used in the several projects now active are characterized by being highly monochromatic. That is, their entire output lies within a very narrow wavelength band. This, together with the added quality of tunability, gives them great flexibility, in applying the strategy which I have just described in order to attain great specificity for any given pollutant.

Before discussing the individual contracts, I would like to spend a moment on the rather high level of apparent redundancy among them. In most of our program we reserve the sponsoring of parallel efforts aimed at a single objective for those needs for which we cannot accept the failure of a single selected approach to reach the objective within a fixed time frame. This is nearly equivalent to saying that redundant strategies are applied only in situations approaching the crisis category. In the present case, that of long path optical measurement, our reason for funding parallel - possibly redundant - efforts is based, not on any overwhelmingly important need, but on the simultaneous emergence of three separate proposals, all already partially developed through other funding, each having about the same probability of success, and each involving a highly specialized technical team that will be disbanded if funding support cannot be provided. Under these circumstances we feel that we are fully justified in supporting all three contractors.

In a contract with the General Electric Company we are investigating the application of gas lasers to long path instrumentation. This effort centers on, but is not restricted to, the carbon dioxide laser. Carbon dioxide when excited within the cavity of a laser initially emits a series of some 70-odd spectral lines in the 9-11 micron region. An external grating and chopper operate to sequence four lines, preselected by computer comparison of all possible lines with the absorbance spectrum of the pollutant of interest (in this case ozone). The four light pulses, each carrying light of its own unique wavelength, exit from the instrument, traverse the atmosphere that is being observed, and are returned (again traversing the same path) by a retroreflector situated some 1 or 2 kilometers away.

Upon returning to the instrument, the intensity of each pulse is measured and compared with that measured for the same pulse a few microseconds earlier on its outward journey. The differences, or attenuations, of all four wavelengths become the coefficients of a set of equations whose solution equals the average ozone concentration along the optical path just described. An on-line computer derives the necessary equations through an empirical calibration procedure and thereafter serves to accomplish their solution.

The instrument that I have described is presently being compared with point-sampling instruments that physically traverse the same path. Assuming reasonable agreement in this test, it is planned to assemble a prototype instrument on a trailer mount and to carry out extensive field evaluation.

A second contract, with the Lincoln Laboratories of Massachusetts Institute of Technology is, in general concept, sufficiently similar to that just described to eliminate the need for a separate overall description. Its most salient feature is the use of a tiny crystal diode laser as its light source, analogous to the gas laser previously described in connection with the General Electric program. Lincoln Laboratories have developed the art of synthesizing such crystals in a form that exhibits spectral resolution several orders of magnitude finer than is possible with gas or other lasers. By appropriate control of composition they can achieve rough tuning close to a desired wavelength, and can perform fine tuning to a precisely selected value by controlling the operating current. Described in simple terms, the resolution of such a laser is to that of a tunable gas laser as the gas laser is to a grating monochromator. Resolution of this order is an extremely powerful tool in attaining the needed single-substance specificity in long-path pollutant measurement, since it multiplies the ability to discriminate against potential interferents. To counterbalance the obvious advantages of Lincoln Labs' diode lasers, we are faced with two principal disadvantages inherent in them. One is that their power output is extremely small, thus requiring the most sensitive light detectors for their utilization--and these must be operated at or near the temperature of liquid helium. The other is that the diodes themselves must be operated at cryogenic temperatures in order to maximize their resolving capability. Fortunately it is possible to mount laser and detector in fairly close physical proximity to one another, so that both demands for cooling can probably be satisfied with a single device. Lincoln is now carrying out studies to determine the optimum tradeoff between cooling requirement and quality of performance of the system. It appears quite likely that they can assemble a system capable of operating on commercially available mechanical refrigeration, thus avoiding the need for supplying liquid helium to a field installation.

A breadboard assembly of Lincoln's best effort to date will be compared with moving point-sampling instruments in a preliminary evaluation scheduled for later this month.

Our third extramural effort in long-path optics consists of a grant to Tulane University. A group under Dr. Hidalgo there is studying gas lasers similar to those being used in the General Electric program. Their effort involves theoretical and experimental application of more sophisticated tuning techniques to the carbon dioxide laser, with their results being checked out through actual measurement of atmospheric ozone and comparison of results with moving point samplers.

A REVIEW OF AVAILABLE TECHNIQUES FOR COUPLING CONTINUOUS GASEOUS POLLUTANT MONITORS TO EMISSION SOURCES

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Chemistry and Physics Laboratory

INTRODUCTION

The state-of-the-art in the development of source level pollution monitors has reached the stage at which several viable detection methods are available. Instrument systems have been designed which are based on either process analyzer concepts or modification of ambient air sensors. Measurement techniques such as nondispersive infrared or ultraviolet absorption have long been incorporated in the analysis of process streams whereas flame photometry, chemiluminescence, and electrochemical transducers have found initial applications in ambient air monitoring instrumentation where high sensitivity is required.

Nearly all of these sensors have the required sensitivity, freedom from interferences, and adequate response time where application for source level pollution monitoring presents no problem on the detectors themselves. But we find that for monitoring stationary sources of gaseous emissions, consideration must be given to the complete monitoring system. Stack emissions usually contain corrosive gases at elevated temperatures. Such streams may have a high dew point temperature or include particulate matter of varying composition and size. A monitoring system must be capable of continuously extracting a sample from these types of sources, transporting it to the detector, and conditioning it, if necessary, for an accurate analysis.

It is important that the extraction, transport, and conditioning of the sample be consistent with the analytical method involved. At present, there are three sampling conditioning techniques available. These consist of: a) a "brute-force" approach; b) dilution techniques; or c) in-situ measurement.

SOURCE LEVEL SAMPLE CONDITIONING

Figure 1 illustrates a typical measurement system for extractive monitors having application for the analysis of SO_2 or oxides of nitorgen from combustion sources. The gas sample is withdrawn from the stack via a filtered-probe and passed through a water removal system (usually a refrigerated dryer) before entering the analyzer itself. For long term operation, the water condensate is continually removed and the probe filter is periodically back-flushed with compressed air to remove entrained particulate matter. The system also contains some provision for the introduction of zero and calibration gases. Several potential sources of error can exist in such a sampling system prior to the instrument detector. Sample integrity can be destroyed by: (1) chemical reaction with surface materials, (2) chemisorption on particulate matter, (3) solution in the water condensate, and (4) leakage of sample lines. The Environmental Protection Agency has contracted an investigation into these problem areas.[1] Hopefully, design criteria can be established for analyzer-interface combinations applied to general stationary source categories.

An extractive monitoring system for combustion sources requiring minimal sample conditioning is illustrated in Figure 2. An air aspirator is utilized to extract a sample from a source on a continuous basis. As our experience has demonstrated that sample pump failure has been a major problem area in continuous source monitoring, the use of aspirators could be advantageous if a source of plant or instrument air is available at the system installation site. This particular system, incorporated as part of a research study discussed later in this paper, is the DuPont 460/1* SO_2 and NO_x analyzer. Stack gas is passed through a heated sample cell positioned between an ultraviolet energy source and a phototube detector. Sulfur dioxide and the nitrogen oxides in the sample gas are analyzed in sequence. A split-beam photometer is utilized by measuring the difference in energy absorption at 280 nm and 436 nm measuring wavelengths and at a 570 nm reference wavelength. The 280 nm wavelength is chosen for SO_2 measurement with the 436 nm wavelength selected for NO_2 measurement. Since nitric oxide has little absorbance in the visible and ultraviolet, conversion to NO_2 is required for its measurement. The system achieves this conversion by reacting NO in the sample with oxygen at high pressure. By measuring the reaction product at roughly 90% completion, a sequential analysis of SO_2, NO_2, and NO can be accomplished every 15 minutes. Between each analysis sequence the gas cell, heated sample line, and probe filter are backflushed automatically with air to remove particulate matter from the system and obtain a "zero" for the photometer.

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* Mention of Company name or product is not intented to constitute endorsement by EPA.

The particular design of an extractive monitoring system depends largely on the characteristics of the emission source. For example, Figure 3 illustrates a typical monitoring system configuration for analyzing the atmospheric emissions from sulfur acid plants. In this arrangement, the probe filter has been eliminated because of the absence of particulate matter in the source emission stream. The filter has been substituted with a coalescing device to collect sulfuric acid mist before contaminating the analyzer. This type of system has been widely used in conjunction with many of the nondispersive infrared analyzers.

SAMPLE DILUTION TECHNIQUES

Dilution techniques can offer an advantage in sample conditioning by eliminating heated sample lines and water vapor removal systems, if the stack gas sample can be quantitatively diluted as close to the source as possible. Such devices are based on controlled flow, permeation sampling, or mechanical means.

Figure 4 illustrates a controlled-flow dilution system for monitoring stationary sources. The stack gas sample is extracted via a filtered probe and transported to the dilution network and analyzer by heat-traced sample line. At this point, the source sample is quantitatively diluted with air by a controlled-flow/orifice combination. In this particular system, sulfur dioxide is measured by a flame photometric detector. Principally, the dilution concept is incorporated in this device to dilute the SO_2 level into a range of linear detector response. The dilution ratio is in the range of 1000 to 1. The sample stream must be filtered from particulates to avoid altering the orifice dimensions which would change the dilution ratio. In addition, a constant temperature must be maintained at the dilution network.

More recently, the controlled-flow approach has been applied to an *in-situ* dilution system.[2] In this application, a specially-constructed sampling probe acts as the orifice but with attainable dilution ratios ranging from 2:1 to 20:1.

Diffusion or permeation sampling devices have been widely reported in the literature.[3,4] A general configuration for such systems is illustrated in Figure 5. A source sample stream is introduced into a chamber divided by a membrane permeable to the gaseous component of interest. Gases permeating the membrane are swept from the chamber by a carrier stream and delivered to the analyzer. Both FEP Teflon and silicone polymers have been used as membrane material for SO_2 and NO dilution. In addition, polymer tubes have been substituted for the membrane. In this manner, the tube is enclosed in a temperature controlled chamber and the sample stream passes over the outer surfaces of the tube with carrier gas flowing through the tube. The desired dilution ratio is dependent upon: (1) the permeability of the membrane or tube to the component of interest; (2) the surface area of the membrane or tube and its temperature; and (3) the volume flow of the carrier gas stream. Systems utilizing this technique are commercially available from several manufacturers. However, the permeation samplers still require extraction of a source sample which must be filtered and held at an elevated temperature prior to entering the diffusion chamber.

Recently, a mechanical device has been developed in our laboratory to quantitatively dilute a source sample in-situ, eliminating the need for heated sample lines and probe filters.[5] The system, illustrated in Figure 6, utilizes a rotating disc containing sample chambers of known volume. The disc is sandwiched between two stationary discs having sample inlet ports to allow gas exchange between the sample chambers and the stack gas environment. In practice, the dilution head is inserted into the emission stream. Rotation of the sample disc effects gas exchange at the sample inlet ports and at a mixing chamber into which a diluent gas is introduced. The diluted sample stream is then analyzed by an ambient air analyzer. The dilution ratio depends upon: (1) the number and volume of sample chambers; (2) the rotational speed of the sample disc; and (3) the volumetric flow of the diluent gas. Operation of the sampler has been demonstrated in the field by the continuous analysis of the SO_2 emissions from a 190 megawatt pulverized coal boiler.

Figure 7 represents a typical 24-hour segment from a week's continuous operation during which the "disc diluter" was coupled to a conductometric ambient SO_2 monitor. The resultant SO_2 emissions, based on a dilution ratio of 1600:1 are plotted against the net load, in megawatts, from the boiler turbine generator. The diluter/analyzer combination appears to follow the trends in power output quite consistently. Further development of the dilution system is being carried out under contract to determine its range of applicability.[6] Also, design modifications have been incorporated to allow in-situ calibration of the dilution head.

IN-SITU MONITORING

In-stack measurement avoids any extraction of sample by utilizing the sample stream itself as an analysis chamber. These instrument systems employ electro-optical detection which can be arranged in three differing configurations.

A folded-path design places the energy source and receiver at the same location. In this manner the energy beam enters the emission stream through a slotted probe and is reflected back into the instrument. For large stack or duct diameters, the pathlength of measurements might be representative of a relatively small portion of the stack diameter.

A double-ended system is one in which the source and receiver are located at opposite ends of the stack diameter. However, some instruments still might require the use of a slotted pipe extending across the stack to either prevent misalignment of the optical beam or restrict the absorption pathlength to maintain a linear detector response.

Recently, an investigation has been completed which compared both extractive and in-situ electro-optical instrumentation for the measurement of SO_2 emissions from a pulverized-coal power generating boiler. An assessment was made of individual system performance under field conditions. To accomplish this, particular areas of interest in this study included: (1) an investigation of the effects of variations in fuel composition, boiler operating conditions, and particulate matter on the various measurement systems; (2) a correlation of instrument response with standard EPA compliance test methods:[7] and (3) a determination of several instrument operating criteria such as zero drift, span drift, and maintenance.

This study was carried out at the Duke Power Company's River Bend Steam Station in Charlotte, North Carolina, from January through March, 1973. Table 1 outlines the instrumentation utilized during the study. Sulfur dioxide levels were simultaneously monitored by three discrete systems. They consisted of the DuPont 460/1 source monitoring system for SO_2, NO, and NO_x; the CEA Mark IV in-situ SO_2 system; and the Bailey Meter Company SO_2 source analyzer. A in-stack transmissometer measuring opacity and a beta-gauge mass particulate monitor which were installed in the source stream as part of parallel research studies in progress at the time provided supporting measurements. An instrument was also used which was able to provide a continuous record of stack gas velocity and temperature.

The instruments and sampling probes were installed in the stack of a 150 megawatt wall-fired boiler. The power generating unit was equipped with both hot and cold electrostatic precipitators containing a total of 14 stages. Therefore, the particulate loading in the stack could be varied in finite increments over a wide dynamic range. A small building was erected at the base of the stack to house the instrument control units and a digital data acquisition system. The output signlas from all of the monitoring devices were coupled to are Esterline-Angus 2020 digitizer with a teletype print out. In addition, each measurement was recorded on stripcharts.

Figure 8 is an illustration of the optics utilized in the CEA in-stack SO_2 correlation spectrometer. In this system, light from a tungsten halogen lamp is collimated and then reflected off the flat zero/read mirror. When this mirror is in the "read" position, light is directed into the probe and the probe mirror directs the light beam back into the spectrometer. If SO_2 is present in the probe slot, it will absorb energy in regularly spaced bands at 3025Å. Light passing through the entrance slit is reflected off the modulator mirror to the diffraction grating. The grating disperses the light, spatially displaying a focussed absorption spectra of SO_2 at the exit mask. The optical center of the modulator mirror is tilted at a slight angle with respect to its axis of rotation, causing the angle at which light strikes the grating to vary as the motor rotates. This in turn causes the absorption spectra to scan the exit mask in a circular fashion, creating a series of harmonics whose intensity represents the SO_2 concentration.

When the zero/read mirror is in the "zero" position, light is redirected into the spectrometer, by-passing the sample probe, to provide a zero check. If a temperature-stabilized gas cell containing a known SO_2 concentration is introduced into the path while the mirror is in the "zero" position, an instrument span check can be made. The output signal is affected by temperature variations of the absorbing gas in the sample slot. The effect is governed by the Charles' Law Relationship and spectral band-broadening at high temperatures. A 6°C change in stack gas temperature alters the output signal by 3 percent. This could be significant in applications in which there are wide fluctuations in the emission temperature.

Figure 9 illustrates the operation of the Bailey SO_2 source monitor. The system consists of a source housing and a receiver. The source contains two hollow cathode lamps, a reference sensor, and optics. The receiver contains another identical sensor. A slotted pipe is provided with a metered flow of purge air to each housing to maintain a definite optical pathlength through the gas to be analyzed. The electronics are contained in a cabinet. The source lamps were chosen to emit ultraviolet energy at two closely spaced wavelengths. In operation, the lamps are pulsed alternately on and off and out of phase with each other. Under these conditions, the sensors are detecting the absorption of UV energy at two discrete wavelengths closely spaced such that the extinction coefficient of particulate matter remains the same. Therefore, the output signals represent the average SO_2 concentration across the pathlength determined by the slotted pipe.

After installation, the instruments were operated continuously for three months. For nearly two-thirds of this period, they were left unattended as an attempt to assess their true reliability in an actual installation. An example of the information being obtained in the program is outlined in Table 2 which summarizes the data from an experiment to determine possible particulate interferences on the measurement systems. In this experiment, the particulate concentration in the stack gas stream was systematically increased to yield a range from 2 1/2 percent through 48 percent stack opacity. During this time, the instruments were operated continuously and the data logger was cycled at 10-second intervals to closely approximate integration of each instrument signal. Concurrently, a series of compliance test (Method 6) samples were taken as a reference. During the course of the experiment, net load of the boiler output increased which resulted in a proportional increase in the SO_2 concentration by some 50 percent as seen from the Method 6 analyses. Throughout the period, data obtained from the DuPont and CEA systems did not show an appreciable effect from the increasing particulate level. However, the Bailey monitor did appear to respond to the changes in opacity since the relative error in SO_2 concentration as measured by the instrument was 28 percent higher than that of the Method 6 sample obtained at a stack opacity of 2 1/2 percent. The relative error shows a consistent decrease with an increasing opacity level to an error of approximately 10 percent at a stack opacity of 47 percent.

At this time, it is felt that the cause of the interference is related to the pulse frequency of the hollow cathode lamps. Data from the in-stack transmissometer indicates that the particulate concentration varies dynamically over very short time intervals. These fluctuations can occur either in or out of phase with the pulsing rate of the Bailey sources. If they occur out of phase, the energy absorbed during the pulse of one source would occur at a higher background of particulate matter relative to the second source, appearing as an erroneous measurement. Figure 10 serves to illustrate this characteristic behavior. In this figure, the transmissometer recording is shown as well as reproductions from the Bailey and CEA stripcharts. The DuPont system did not contain a continuous recorder because of its sequential operation. The analyzer's SO_2 analysis sequence was held for the experiment and the data logger output for the DuPont instrument was used to represent its analysis in Figure 10. At the present time, reduction of all of the monitoring data is underway and will be presented in a future publication. In addition, a similar study has been planned for the fall of 1973 to investigate the performance of certain in-situ and extractive NO and NO_2 monitoring systems.

SUMMARY

In summary, we have seen that there are several approaches which one can take to continuously monitor a gaseous source emission stream. The extractive approaches involve certain degrees of sample conditioning dependent upon not only the nature of the emission source, but also the detection technique being employed. The conditioning techniques include filtered probes, heated sample lines, water vapor removal systems, or a variety of dilution devices coupled to ambient air monitors. Dilution systems might offer the advantage that both ambient air and source monitoring could be accomplished by the same instrument. A recent investigation has demonstrated the viability of in-situ monitoring for SO_2 which, in effect, eliminates all sample conditioning.

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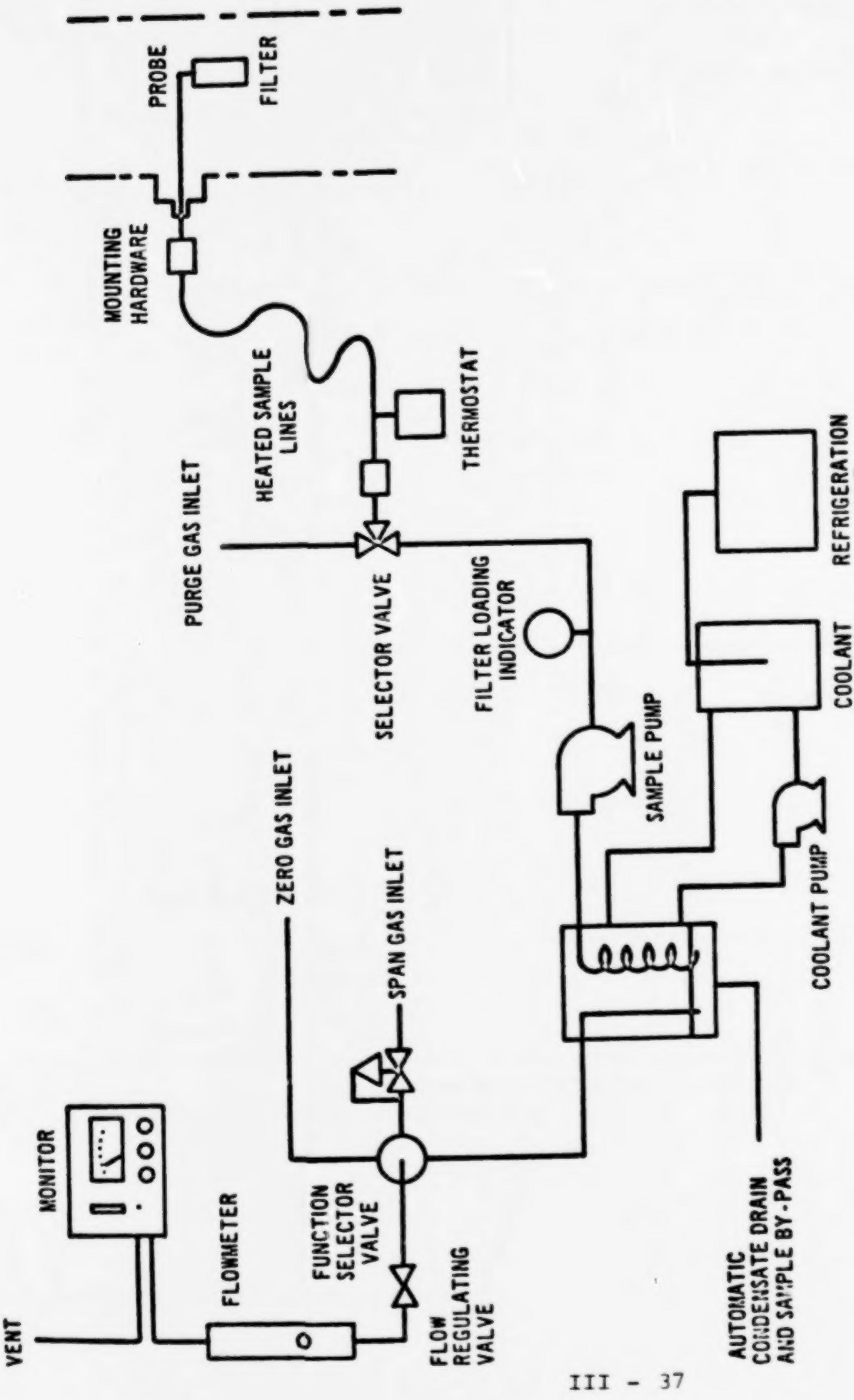
FIGURES

Figure 1. Typical Measurement System for Combustion Sources.
Figure 2. "Pumpless" Monitoring System.
Figure 3. Sulfuric Acid Plant Monitoring System.
Figure 4. Controlled-Flow Dilution System.
Figure 5. Diffusion Diluter/Analyzer Network
Figure 6. Disc Diluter
Figure 7. SO_2 Concentration, ppm vs Net Load, Mw, March 17, 1972.
Figure 8. CEA-MK IV In-Stack SO_2 Monitor.
Figure 9. Bailey SO_2 Source Analyzer.
Figure 10. SO_2 Concentration, ppm and Stack Opacity, %, 0900-1400, March 1, 1973.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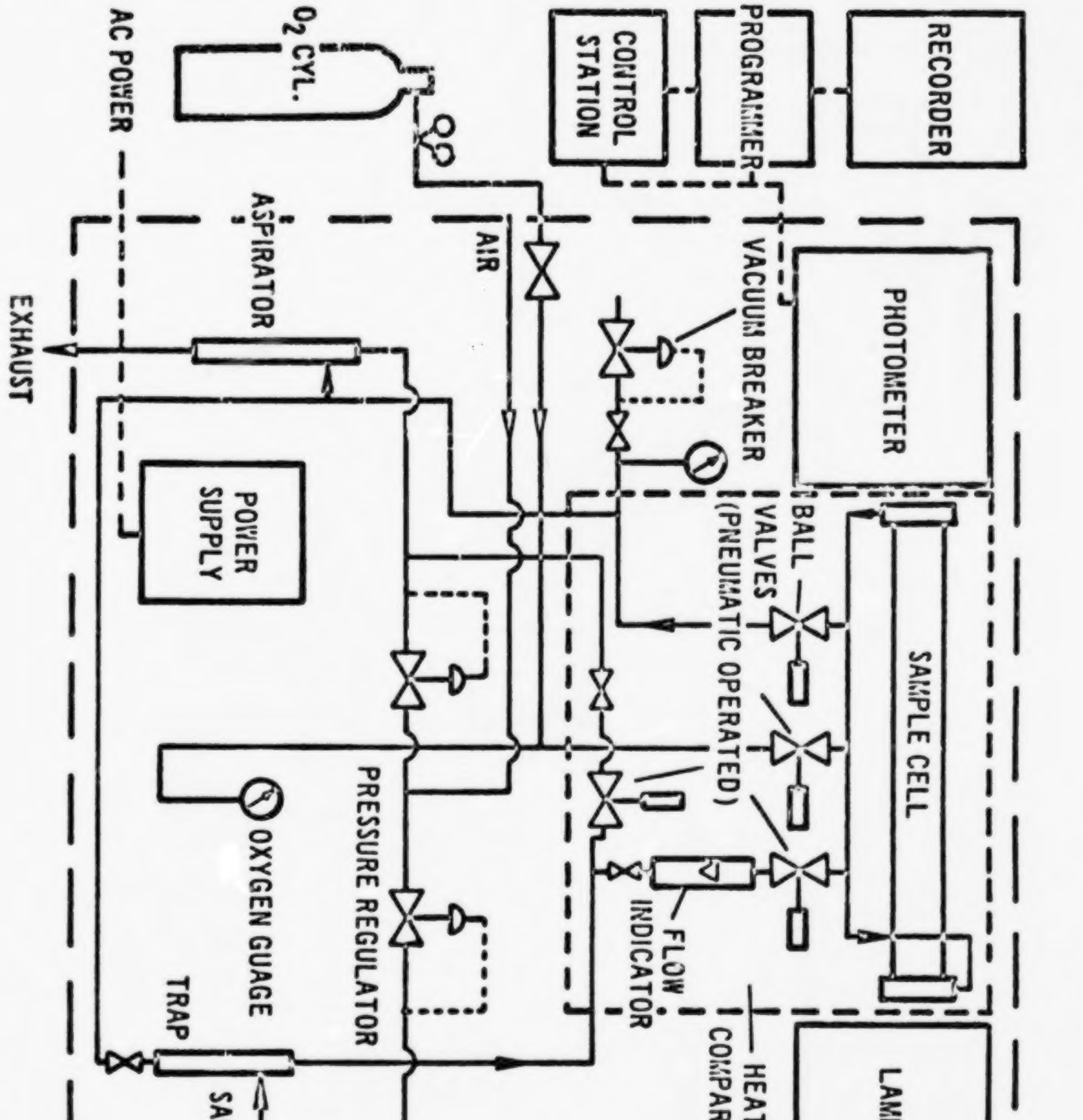
MOUNTING HARDWARE
HEATED SAMPLE LINES
THERMOSTAT
PURGE GAS INLET
SELECTOR VALVE
FILTER LOADING INDICATOR
SAMPLE PUMP
REFRIGERATION UNIT
COOLANT RESERVOIR
COOLANT PUMP
ZERO GAS INLET
SPAN GAS INLET
MONITOR
FLOWMETER
FUNCTION SELECTOR VALVE
FLOW REGULATING VALVE
VENT
AUTOMATIC CONDENSATE DRAIN AND SAMPLE BY-PASS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BALL VALVES (PNEUMATIC OPERATED)
SAMPLE CELL
PRESSURE REGULATOR
OXYGEN GUAGE
TRAP
FLOW INDICATOR
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TO ELEC SOLENOIDS
SAMPLE IN
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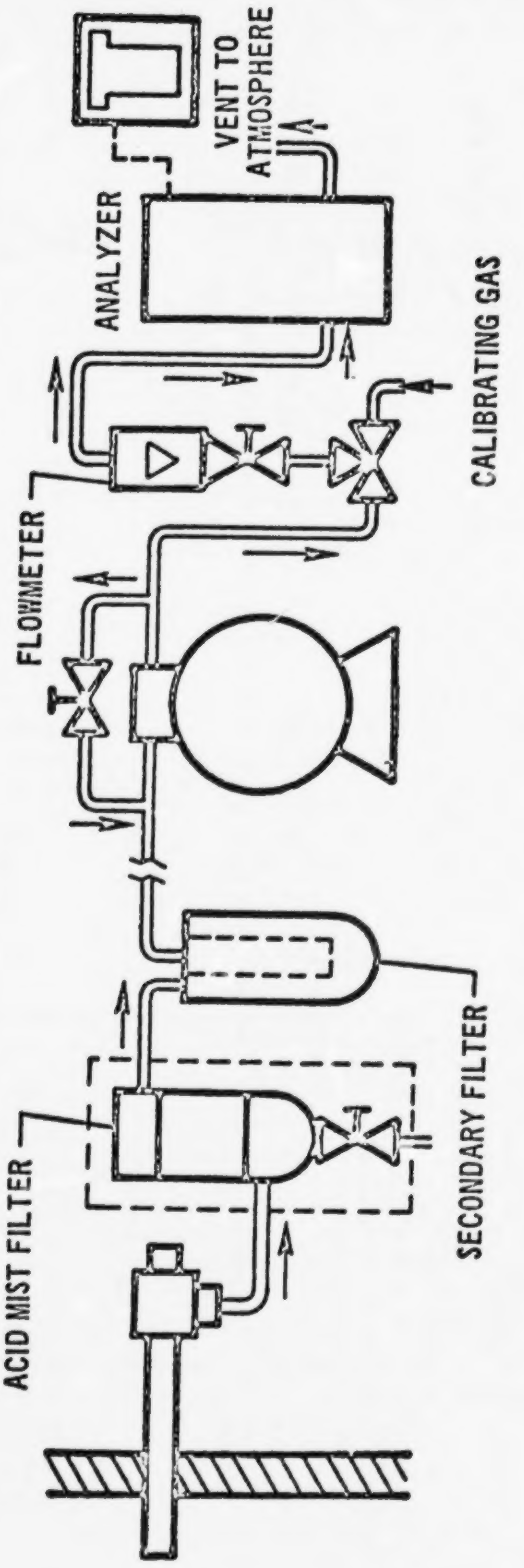
FILTER PROBE
STACK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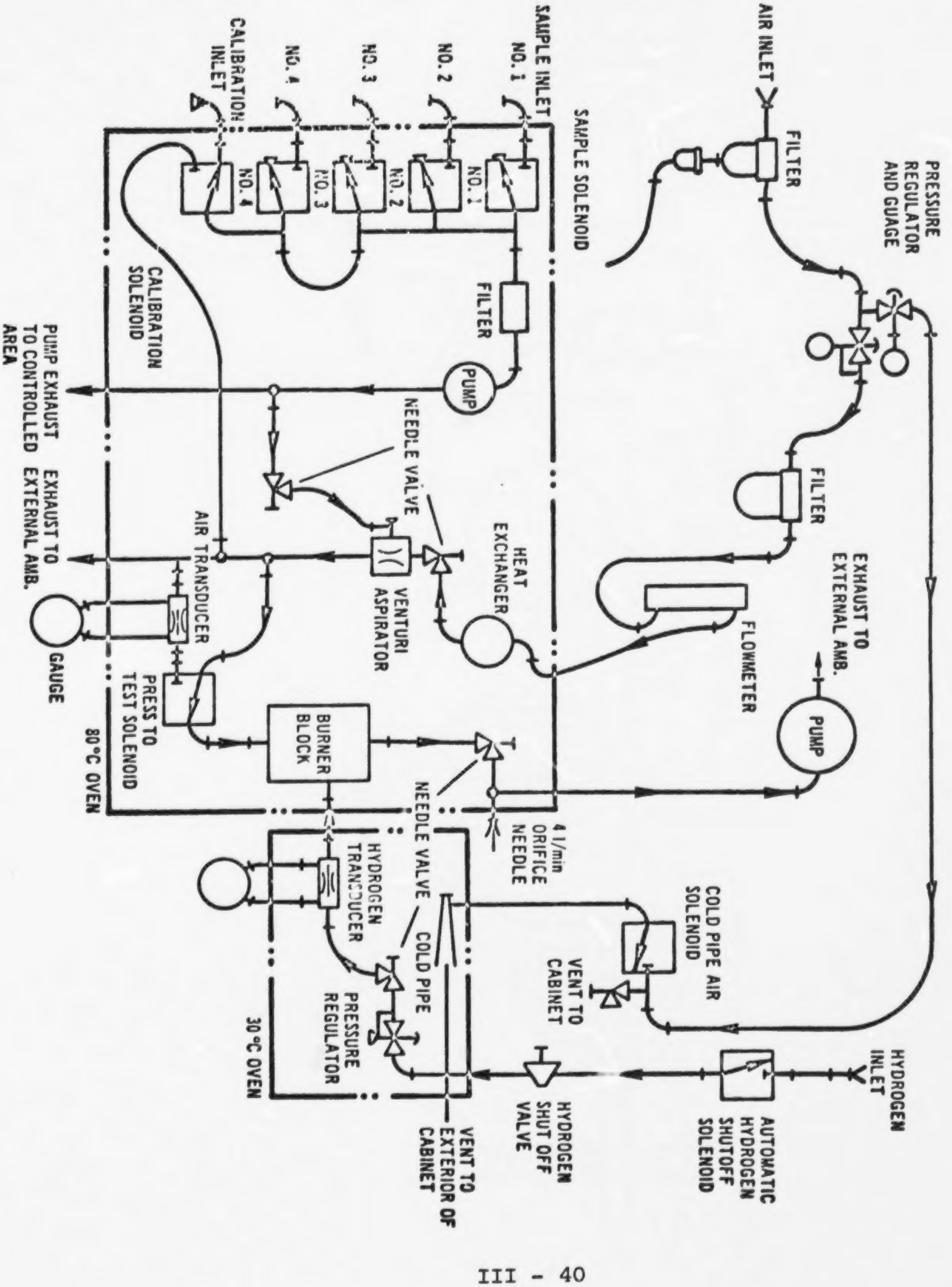
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NO. 3
NO. 4
CALIBRATION INLET
NO. 1
NO. 2
NO. 3
NO. 4
FILTER
PUMP
CALIBRATION SOLENOID
NEEDLE VALVE
VENTURI ASPIRATOR
AIR TRANSDUCER
GAUGE
PRESS TO TEST SOLENOID
BURNER BLOCK
NEEDLE VALVE
4 l/min ORIFICE NEEDLE
PUMP EXHAUST TO CONTROLLED AREA
EXHAUST TO EXTERNAL AMB.
80°C OVEN
HYDROGEN TRANSDUCER
COLD PIPE
COLD PIPE AIR SOLENOID
VENT TO CABINET
PRESSURE REGULATOR
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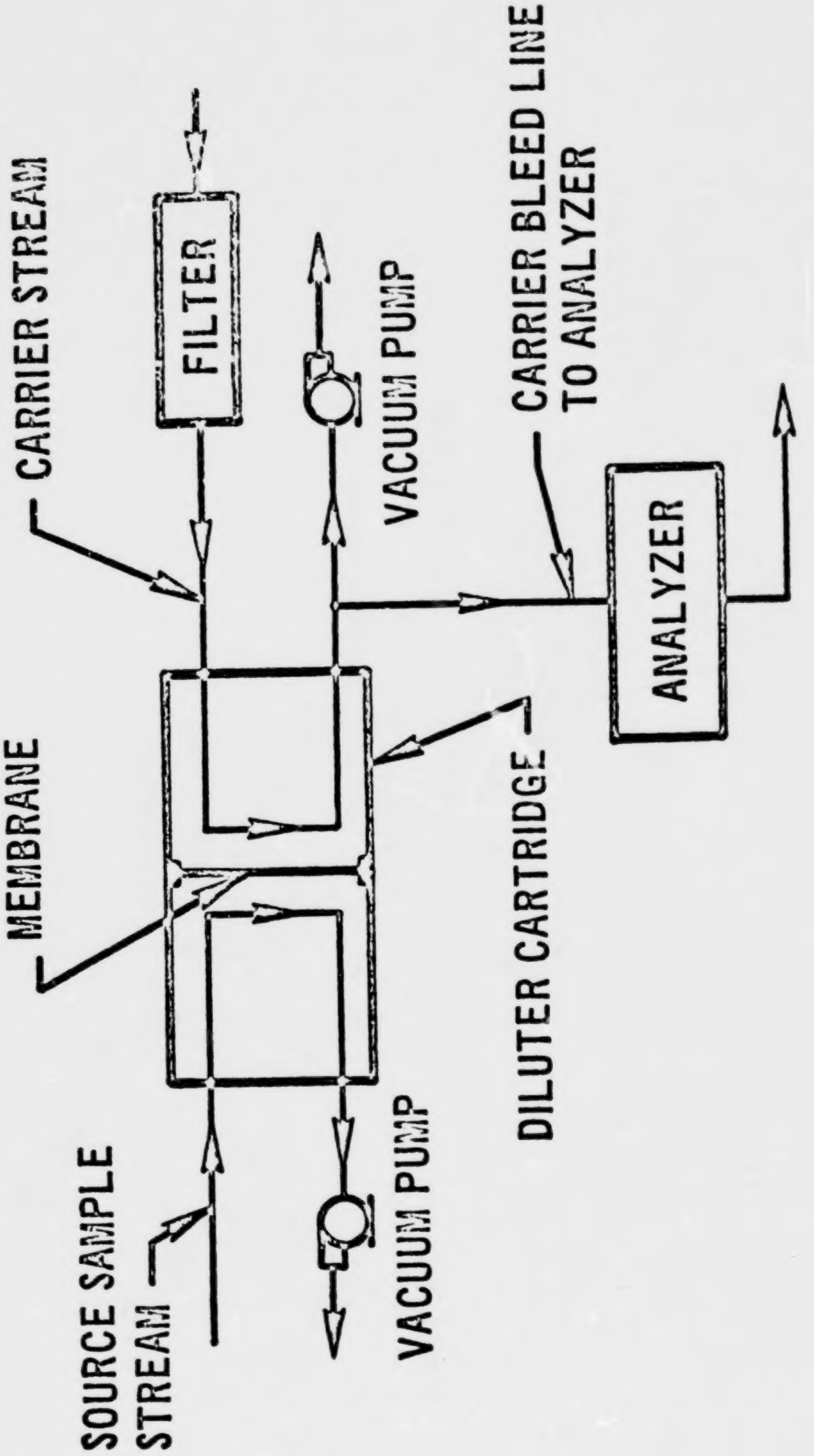
HYDROGEN INLET


CARRIER STREAM
FILTER
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TO ANALYZER
ANALYZER
MEMBRANE
DILUTER CARTRIDGE
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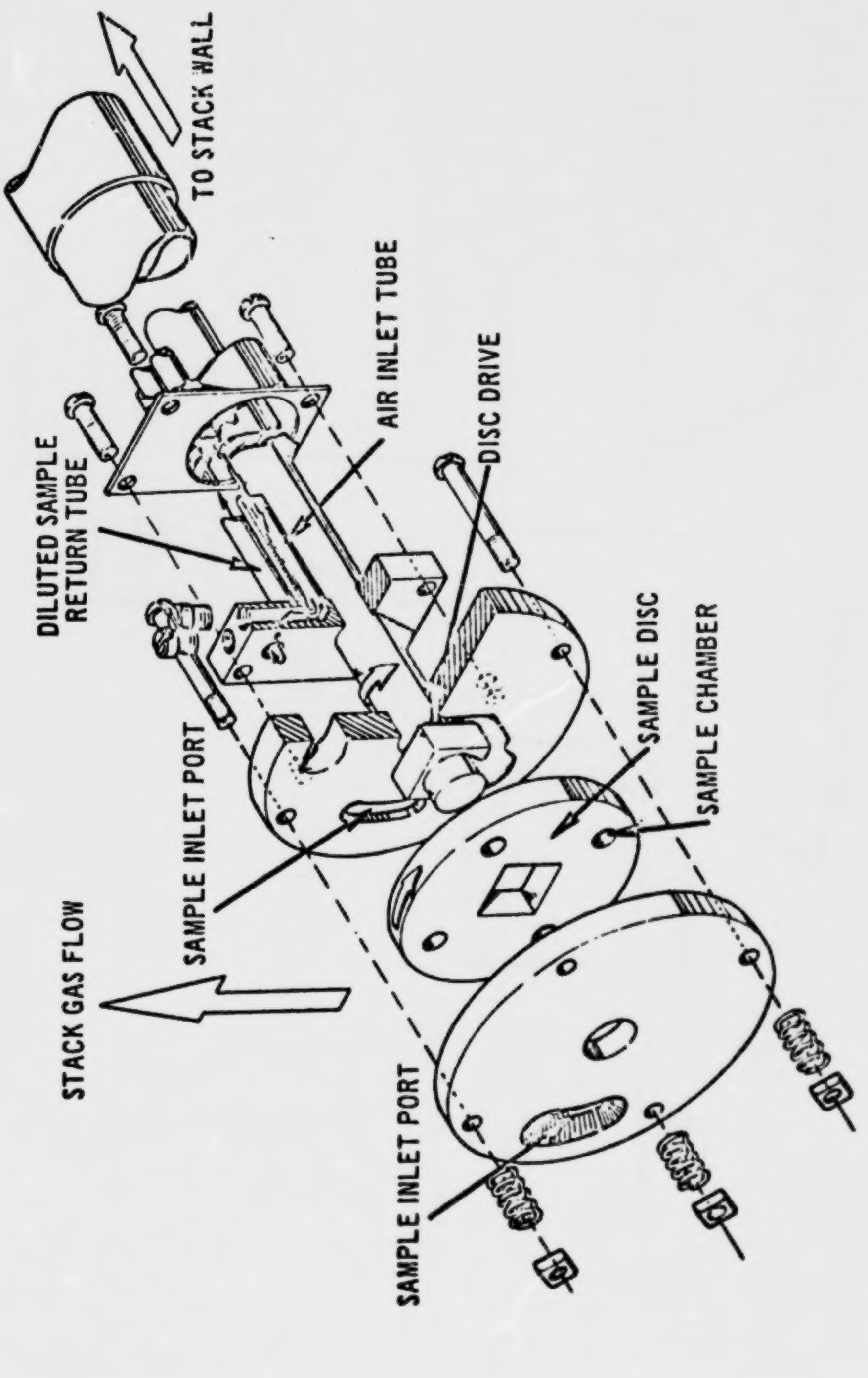
STREAM
VACUUM PUMP


TO STACK WALL
DILUTED SAMPLE RETURN TUBE
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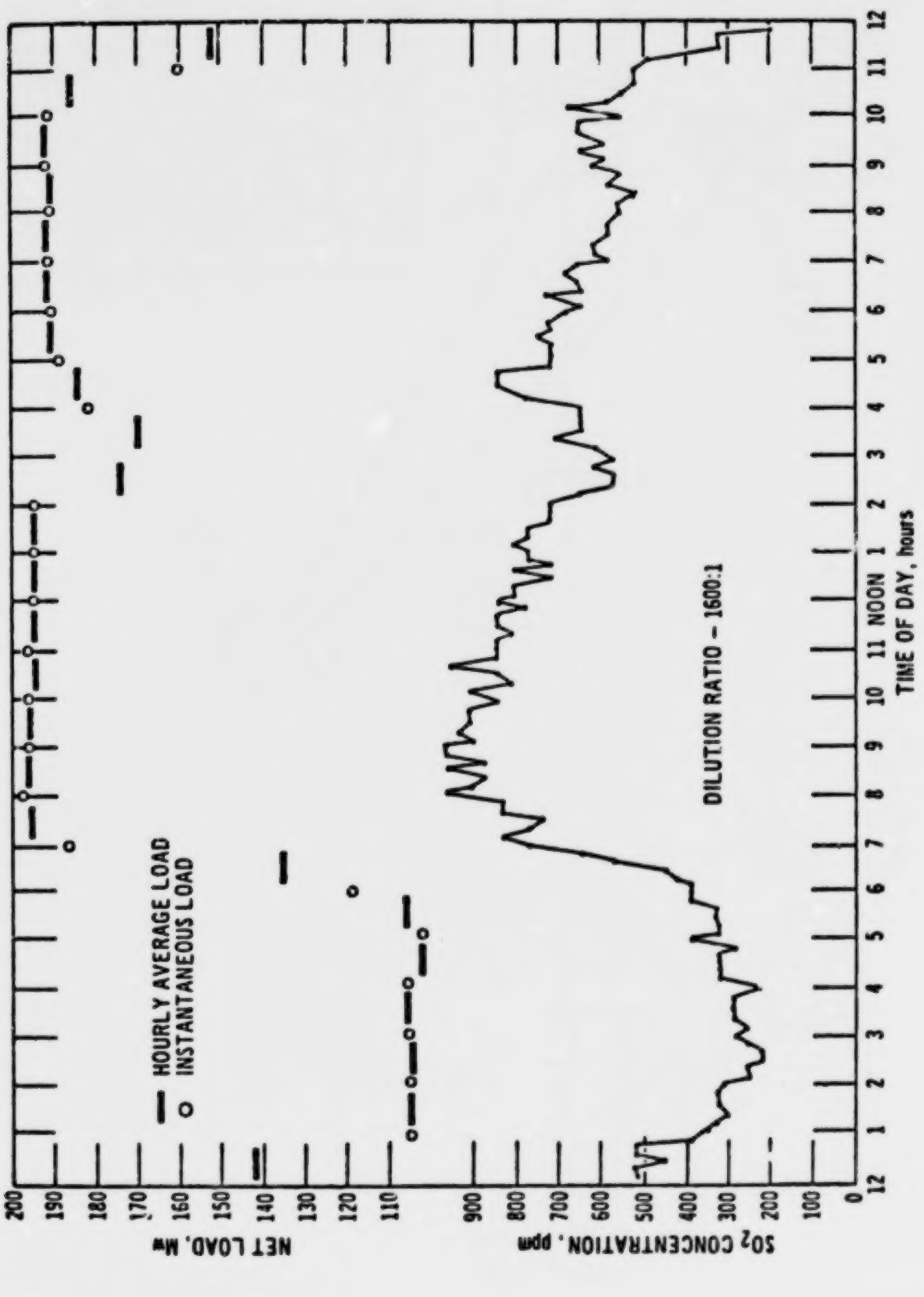
DISC DRIVE
SAMPLE INLET PORT
SAMPLE DISC
SAMPLE CHAMBER
STACK GAS FLOW
SAMPLE INLET PORT


HOURLY AVERAGE LOAD
INSTANTANEOUS LOAD
NET LOAD, Mw
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190
180
170
160
150
140
130
120
110
SO$_2$ CONCENTRATION, ppm
900
800
700
600
500
400
300
200
100
0
DILUTION RATIO - 1600:1
12
1
2
3
4
5
6
7
8
9
10
11
NOON
1
2
3
4
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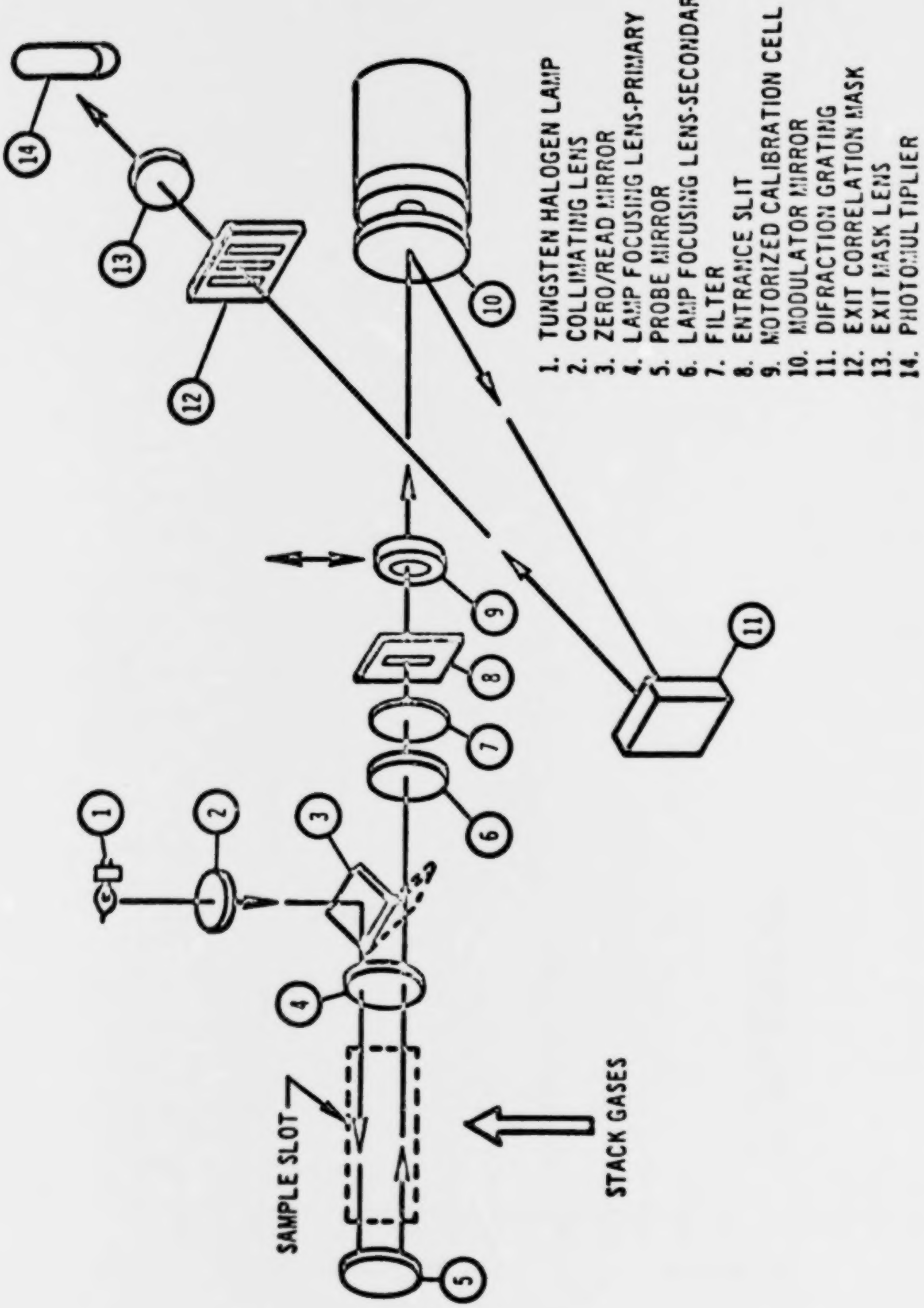
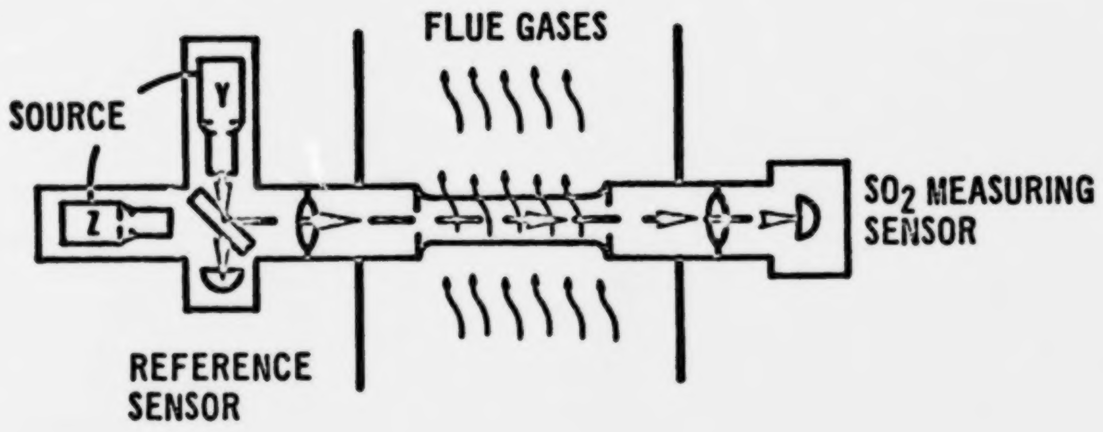
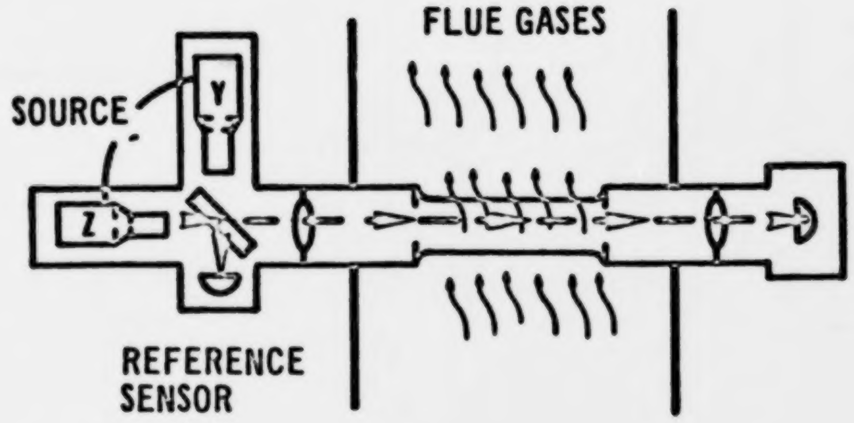
9
10
11
12
TIME OF DAY, hours


SAMPLE SLOT
STACK GASES
1. TUNGSTEN HALOGEN LAMP
2. COLLIMATING LENS
3. ZERO/READ MIRROR
4. LAMP FOCUSING LENS-PRIMARY
5. PROBE MIRROR
6. LAMP FOCUSING LENS-SECONDARY
7. FILTER
8. ENTRANCE SLIT
9. MOTORIZED CALIBRATION CELL
10. MODULATOR MIRROR
11. DIFRACTION GRATING
12. EXIT CORRELATION MASK
13. EXIT MASK LENS
14. PHOTOMULTIPLIER



FIRST HALF CYCLE



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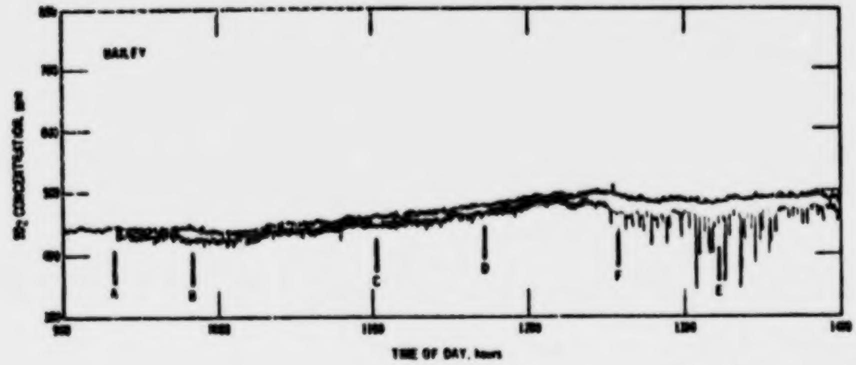
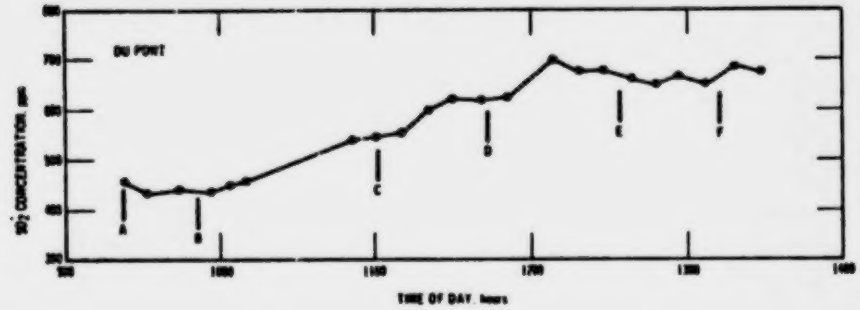
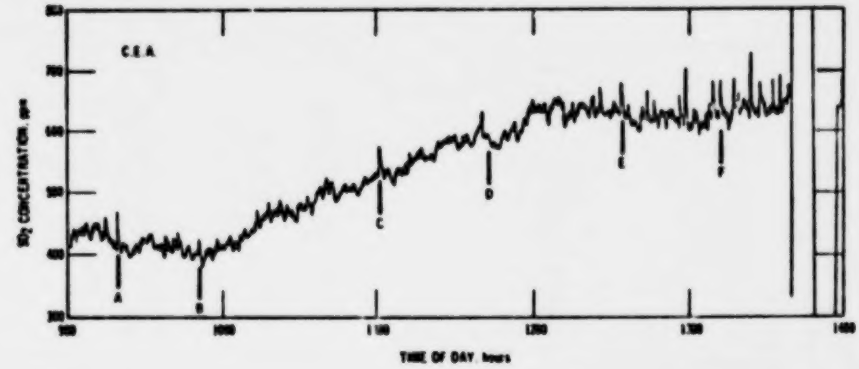


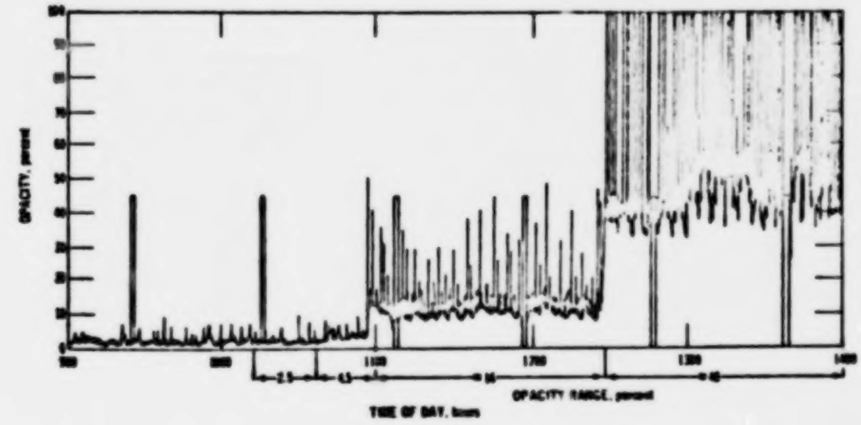
BAILEY
SO2 CONCENTRATION, ppm
800
700
600
500
400
300
A
B
C
D
F
E
900
1000
1100
1200
1300
1400
TIME OF DAY, hours



DU PONT
SO2 CONCENTRATION, ppm
800
700
600
500
400
300
A
B
C
D
E
F
900
1000
1100
1200
1300
1400
TIME OF DAY, hours



C.E.A.
SO2 CONCENTRATION, ppm
800
700
600
500
400
300
A
B
C
D
E
F
900
1000
1100
1200
1300
1400
TIME OF DAY, hours



OPACITY, percent
100
90
80
70
60
50
40
30
20
10
0
900
1000
1100
1200
1300
1400
2.5
4.5
16
40
OPACITY RANGE, percent
TIME OF DAY, hours

Table 1. Instrumentation Utilized During Study, January 1-April 1, 1973.

Table 2. Effect of Increasing Stack Opacity on Instrument Response, March 1, 1973.

INSTRUMENTATION UTILIZED DURING STUDY

A. SO_2 MEASUREMENT
   1. DUPONT 460/1 SOURCE MONITORING SYSTEM
   2. CEA/BARRINGER MK-IV SO_2 STACK MONITOR
   3. BAILEY METER CO. SO_2 STACK MONITOR

B. SUPPORTING MEASUREMENTS
   1. EPA METHOD 6-SO_2
   2. EPA METHOD 5-MASS PARTICULATES
   3. TRANSMISSOMETER-OPACITY
   4. BETA GAUGE-MASS PARTICULATES
   5. PMC AUTOPITOMETER-CONTINUOUS STACK GAS VELOCITY, TEMPERATURE

C. DATA ACQUISITION
   1. EA 2020 + TELETYPE
   2. STRIPCHART RECORDERS

SAMPLE	OPACITY	METHOD 6	DuPONT	CEA MKIV	BAILEY SO_2
A	2.5%	460PPM	451, - 1.9%	424, - 7.8	590, +28.2
B	3.0	475	438, - 7.8	416, -12.4	570, +20.0
C	15.0	675	577, -14.5	550, -18.5	680, + 0.7
D	17.5	619	632, + 2.1	599, - 3.2	720, +16.3
E	45.0	661	664, + 0.5	624, - 5.5	730, +10.4
F	47.5	682	678, - 0.6	638, - 6.4	750, + 9.9

SESSION IV

WATER QUALITY SENSOR DEVELOPMENT

CHAIRMAN

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NERC-CINCINNATI

ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
OFFICE OF MONITORING SYSTEMS

INSITU SENSOR SYSTEMS FOR WATER QUALITY MEASUREMENT

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Presented at the "Second Conference On Environmental Quality Sensors", October 10 - 12, 1973. National Environmental Research Center, Las Vegas, Nevada.

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I - INTRODUCTION

Monitoring is defined by the United Nations as the "process of repetitive observing for defined purposes of one or more elements or indicators of the environment according to pre-arranged schedules in space and time, and using comparable methodologies for environmental sensing and data collection." Present trends in pollution control activities indicate an increasing reliance on automated quality monitoring systems. This stems from the fact that manual measurements are, for the most part, inefficient and limited by the frequency with which samples can be collected for analysis. The time delay between sampling and analysis can result in certain changes in the characteristics of the sample, causing it to be less representative of the water body from which it was collected. The time involved in making and reporting the analysis is also time lost before any water pollution corrective action can take place. In addition, when viewed in relation to the availability and cost of labor, automatic monitoring systems are considered to be the least costly system. Nevertheless, our justification of automatic monitoring systems should be accompanied by a realization of the limits of dependency on such systems.

Generally speaking, automatic monitoring techniques can be categorized into non-contact remote sensing procedures and contact in-situ or on-line continuous or discrete sample analyses.

Remote sensing techniques are based on the measurement of electromagnetic radiation reflected from the surface of water bodies over large geographical areas. The concept of remote sensing using aerial surveillance is most appealing from cost viewpoint. Unfortunately, the technique suffers from certain limitations, i.e.

(a) detection is limited to a small number of quality characteristics, (b) results usually exhibit poor accuracy and precision and (c) measurements are essentially confined to the survace properties of water. Nevertheless, remote sensing has been used with various degrees of success to measure temperature, oil, chlorophyll, turbidity, and color. Typical applications include (a) location and typing of waste outfalls, (b) assessment of oil spills, (c) algal biomass estimation, (d) selection of sampling sites, and (e) identification of mixing zones. Detailed discussion on this subject can be found elsewhere (1, 2, 3).

Insitu monitoring techniques rely on the direct placement of the sensor in the environment to be measured. Consequently the sample step is eliminated and the sensor response will be proportional to certain physical or chemical characteristics of the acqueous phase according to established relationships. It should be realized, however, that in-situ sensor responses may be significantly influenced by water flow, temperature and a number of chemical and biological interferences which may prevail at the monitoring site. These factors should be taken into consideration whenever in-situ measurements are concerned.

On-line automated analyses are based on withdrawing water from a given site, either as a continuous stream or discrete samples, and allowing it to flow through the sensor system. This may be done with or without sample pretreatment. Sample pretreatment may include temperature control, filtration, extraction, dissolution, dilution, digestion and reagent a-ditions. In fact most of the procedures which are usually carried out by an analyst, are automated and performed on a stream of samples moved by a fixed-speed peristaltic pump, e.g. the Technicon Auto-Analyzer (4). A schematic diagram of basic Auto-Analyzer operations, and a listing of parameters for which automated procedures are available are shown in Appendix A. Auto-Analyzer techniques find widest application in laboratory operations where large samples of water are handled daily.

There have been certain attempts, however, to use this technique for water quality monitoring where the autoanalyzer is kept in a trailer on a river bank or on board ship. The reader is advised to consult the following references for typical applications of Auto-Analyzer techniques 4, 5.

Discussions in this paper are primarily concerned with a number of electrochemical sensors applicable to in-situ as well as on-line monitoring procedures. This includes descriptions of currently available and newly developed sensors and typical monitoring applications.

II - SENSOR PERFORMANCE CHARACTERISTICS

In monitoring systems the most critical part is the sensor system and the reliability of measurement is mostly dependent on the reliability of the sensor system. This is true whether the sensor is an electrode, a thermistor or a photoelectric cell. A clear understanding of the operation characteristics of the sensor and its dynamic response is essential. This is based on proper calibration, servicing, maintenance and alertness for small clues that may indicate malfunction.

Primary sensor characteristics are defined in terms of (a) sensitivity, (b) response time, (c) selectivity, (d) long term stability, (e) accuracy, and (f) precision. Secondary sensor characteristics are those which define the environmental effects, e.g. (a) temperature, (b) hydrostatic and hydrodynamic forces, (c) ionic strength, (d) pH, (e) sunlight, etc.

1 - Primary Sensor Characteristics:

Sensitivity is usually defined in terms of the smallest change in the measured variable that causes a detectable change in the indication of the instrument. It specifies the lower limit of detection of the sensor. Sensitivity is directly proportional to the slope of the curve relating the signal magnitude to the amount of detectable material present. This will reflect directly on the ability to ascertain a difference between the signal and backgroun noise at the detection limit, i.e. given adequate precision, the greater the sensitivity, the better the tdetectability.

The limit of detection of analytical method is the lowest concentration whose signal can be distinguished from the blank signal. This value depends on the sensitivity of the method, as well as the signal-to-noise ratio required to discern the response due to a sample. Advances in electronics have brought about the design of instruments with greater inherent stability and, therefore, lower limits of detection. Use of an on-line digital computer in fast-sweep derivative polarography has permitted the resolution of closely spaced peaks and extended the analytical sensitivity of the technique by more than an order of magnitude.

The speed of the sensor response to changes in the test solution is referred to as the "response time." It is an indication of the time needed for the sensor signal to follow 90, 95 or 99 percent of instantaneous full scale change in the measured variable. The response time should be specified for each sensor indicating whether it is dynamic or static sensor response.

Selectivity of the sensor refers to the effect of interferences resulting from detectable ions or molecules other than the species of interest. Since all sensor systems cannot achieve absolute or 100 percent selectivity, then it is important to specify the selectivity limitations in a given test solution. If the type and amount of the interfering species are known, then it is possible to incorporate the term "selectivity coefficient" in the sensors sensitivity expressionn. Also, in certain cases it is possible to incorporate interferences effects in the sensor calibration curve. This can be done by means of the standard addition technique where known amounts of the measured ions are added to the test solution and the proportional signal values are recorded.

Long term stability usually refers to the change in the sensor's performance characteristics with time. This is used to decide on the frequency of checking the calibration or servicing the sensor. Long term stability is a property of the particular system and is dependent on the presence of interferences and the physiochemical characteristics of the test solution.

Drviations of results by a given sensor from the "true" value define the accuracy of the system. If the source of error is found, and it is possible to correct for it, this is called "determinate error." If the deviation from the true value is compounded indiscriminately by many small errors, it is simply a "random error." Random errors are subject to statistical treatment of the data.

Precision is defined in terms of the reproducibility of the sensor measurement. The more scatter in successive readings, the less precise are the measurements. Usually, precision is closely identified with random errors and statistical theories.

2 - Secondary Sensor Characteristics:

Secondary sensor characteristics refer to the effect of environmental variables. This can be a result of changes in the sensors primary characteristics or changes in the physiochemical characteristics of the test solution. For example, temperature -ffects on conductance measurement are quite complex since the temperature coefficient is dependent on both ionic strength and temperature. The conductivity of sea water was found to increase by 3 percent per degree increase in temperature at 0°C, 2 percent increase at 25°C and about 5 percent increase at 30°C. It is therefore advisable to measure relative conductance than absolute values. This is done by measuring the ratio of the conductance of the test solution to that of a reference solution at the same temperature. Thermistors or resistances can be used instead of the reference solution.

It is always advisable to establish the primary and secondary sensor characteristics for each sensor independently before using it for field applications. Not only these characteristics will vary from one sensor type to another, but also differences between two sensors of the same type and from the same manufacturer may occur.

III - IN-SITU SENSOR SYSTEMS

Currently available in-situ electrochemical sensor systems applicable to water quality monitoring are given in Table I. This includes conductometric, potentiometric, and voltammetric electrode systems. Potentiometric systems include the glass electrode for pH measurement, inert metal electrode (platinum or gold) for the measurement of oxidation-reduction potentials and potentiometric membrane electrodes which will be discussed later.

Workers in the field have expressed doubts regarding the utility of oxidation-reduction potential measurements in surface waters. In fact, only under anoerobic conditions (anoxic waters), and in certain industrial waste effluents, can such measurements give meaningful results.

1 - Oxygen Membrane Electrodes:

At the present time it appears that voltammetric membrane electrodes are the only available sensors capable of in situ analysis of dissolved. The unique features of such electrode systems is that the membrane separates the electrode from the test solution. Two main types are presently available, the voltammetric type and the galvanic cell type (6). The two types are similar in operating characteristics; in the voltammetric type an appropriate potential source is needed, however, while the galvanic type is basically an oxygen energized cell.

Oxygen membrane electrodes have three main components: the membrane, the oxygen-sensing element, and the electrolyte solution. The membrane, the unique feature in such electrode systems, serves in three different capacities.

Table 1. Electrochemical Sensors

Type		
(a) Conductometric	$L = K_c \sum_{i}^{n} C_i \lambda_i z_i$	(1)
(b) Potentiometric	$E_m = \text{constant} + \frac{RT}{zF} \ln \left[a_i + K_J a_J^{z_i/z_j} \right]$	(2)
1. Glass Electrode	$pH = -\log a_{H^+}$	(3)
2. Inert Metal Electrode (Redox Potential)	$pE = -\log a_e = E_H/(2.3\ RTF^{-1})$	(4)
3. Potentiometric Membrane Electrodes	$\text{Cationic} = pM^+ = -\log a_{M^+}$	(5)
	$\text{Anionic} = pA^- = -\log a_{A^-}$	(6)
(c) Voltammetric Membrane Electrodes (Dissolved Oxygen)	$i_d = \left[zFAP_m \frac{1}{b} \right] a_{O_2}$	(7)

L = specific conductance

K_c = cell constant

C_i = ionic concentration

λ_i = ionic equivalent conductance

z_i = ion valency

E_m = measured electrode potential

F = the Faraday constant

K_j = selectivity coefficient

i_d = diffusion current

A = electrode surface area

P_m = membrane permeability coefficient

b = membrane thickness

First, the membrane acts as a protective diffusion barrier separating the sensing element from the test solution. Since plastic membranes are permeable to gases only, oxygen molecules pass through, but electroactive and surface-active contaminants present do not. The possibility of poisoning the sensing element is thus minimized.

Second, the membrane serves to hold the supporting electrolyte in contact with the electrode system and thus makes it possible to determine oxygen in gaseous samples as well as in nonaqueous solutions such as industrial wastes. The third advantage is that the membrane constitutes a finite diffusion layer, the thickness of which is independent of the hydrodynamic properties of the test solution.

A detailed discussion of the principle, operating characteristics, applicability, and limitations in the use of oxygen membrane electrodes may be found elsewhere (6).

Polymeric membranes used with oxygen membrane electrodes show selective permeability to various gases and vapors. Gases reduced at the potential of the sensing electrode (e.g., SO_2 and halogens) cause erroneous readings, but these gases rarely exist in a free state in aqueous systems. Other gases capable of permeating plastic membranes may contaminate the sensing electrode or react with the supporting electrolyte, e.g., CO_2 and H_2S.

Oxygen membrane electrode systems have been used extensively in laboratory and field analysis as well as for continuous monitoring purposes. Some of the main operational problems associated with the use of these electrode systems have been the effect of mixing in the test solution on the electrode sensitivity and short term stability which necessitates frequent calibration. In monitoring operations, the accumulation of inert or biological material on the membrane surface has caused a lot of nuisance. In addition, it has been practically impossible to reproducibly change and mount the membranes without a change in the membrane thickness and permeability characteristics.

As indicated in equation 7 the steady state diffusion current i_d is directly proportional to the activity of molecular oxygen, a, and not necessarily to the concentration, C. The activity and concentration terms are interrelated by the following equation

$$a = \gamma C \tag{8}$$

where γ is the activity coefficient of molecular oxygen. It is only under ideal conditions where γ will be equal to unity and the activity can be replaced by concentration in euqation 7. For example in estuarine and sea waters or brine wastewaters γ will be greater than unity - a phenomenon described as the "salting-out"effect. Also, the presence of soluble organic matter in the test solution, e.g. alcohol, will result in γ values less than unity - a phenomenon described as the "salting-in" effect. Accordingly, the application of the oxygen membrane electrode in natural and wastewater should take account of these factors.

The salting-out effect can be expressed as follows:

$$\ln \gamma = K_s \ I \tag{9}$$

where K_s is the salting out coefficient and I is the ionic strength. By substitution of 8 and 9 in 7, it follows that

$$i_d = \left[n \ FAP_m \ \frac{1}{b}\right] e^{K_s I} \ C \tag{10}$$

Equation 10 can be reduced by introducing the proportionality constant ϕ_a in replacement of term in brackets in equation 10,

$$i_d = \phi_a \ e^{K_s I} \ C \tag{11}$$

Ionic strength values can be approximated by measurement of electrical conductance, using K_s' as a proportionality coefficient,

$$i_d = \phi_a \, e^{K_s' I} \, C \tag{12}$$

where L is the specific conductance of the test solution. Equation 12 offers a simple relationship to compensate for the salting-out effect using specific conductance measurement. This compensation can be done automatically by a simple analog circuit (6).

The main operational problems with available dissolved oxygen electrode systems are (a) lack of stability, (b) easy fouling of the membrane and loss of sensitivity, (c) dependency of sensitivity on flow, and (d) the poisoning effect of H_2S. Regardless of these limitations, dissolved oxygen probes are widely used, and with some extra effort in maintenance and checking, they yield reliable data.

Recent studies in this laboratory resulted in the development of an advanced dissolved oxygen electrode system which does not suffer from the above mentioned limitations (7,8). The newly developed dissolved oxygen probe utilizes a three electrode voltammetric membrance cell of a special design. Measurement is conducted in the form of pulse voltammetry at a predetermined frequency according to the following relationship

$$i_p = zFA\left[\frac{D_f}{\pi t}\right]^{0.5} a_{O_2} \tag{13}$$

where D_f is oxygen diffusivity coefficient in the inner electrolyte solution layer and t is the pulse time. A comparison between equations 7 and 13 indicates that the pulse current, i_p, is neither dependent on the membrane thickness, b, nor on the membrance permeability coefficient, Pm. At appropriate pulse frequency, the electrode sensitivity will not be influenced by depositions on the membrance surface (fouling) and will be independent of mixing of the test solution. In addition, for the same dissolved oxygen content i_p is approximately a hundred times greater than i_d.

To this end, the pulse oxygen membrane electrode is capable of exhibiting much higher sensitivity and more stable performance characteristics than the presently available steady state systems.

2 - Specific Ion Electrodes:

Perhaps the most significant advances in electrochemical sensor development in the last decade or two, is the emergence of potentiometric membrane electrode systems, commonly referred to as specific ion electrodes or selective ion electrodes. These electrode systems offer the possibility of monitoring a wider range of anions and cations in natural and waste waters. The oldest of these electrodes is the pH glass electrode which is available from a variety of sources in the United States. pH electrodes with documented characteristics are available from Beckman Instruments, the Coleman Division of Perkin Elmer, Corning Glass Works, Leeds and Northup, Sargent Company, and H. A. Thomas, to mention the main suppliers. European products include Radiometer in Denmark.

Glass electrodes responsive to monovalent ions, e.g. sodium, potassium, silver, ammonium, are made by Corning Glass Works, Beckman Instrument and Orion Research. Recently developed solid state specific ion electrodes including single crystal, cast disk, or pressed pellet types are available from Orion Research, Beckman Instrument, and Coleman Division of Perkin Elmer. Liquid ion exchange electrodes are also available from Corning Glass Works, and Orion Research. Heterogeneous membranes of the Pungor type are available from Radelkis Electrochemical Instruments in Budapest, through National Instrument Laboratories, Rockville, Maryland. Specific Ion Electrodes are also produced by Radiometer in Denmark, Crytur in CSSR, and Phillips in Holland.

Specific ion electrodes of interest to water quality monitoring can be conveniently classified into (a) solid state, (b) liquid ion exchange and (c) gas responsive electrode systems.

a. Solid State Specific Ion Electrodes

In these electrode systems the membrane contains a fixed sum of certain kind of ions, the structure of which is constant in time. The solid ion exchange membranes can be either homogeneous (single crystal, a crystalline subjstance in a disk or pellet form, or glass which is considered to be solid with regard to the immobility of the ionic groups), or heterogeneous, where the crystalline material is included into a matrix made from suitable polymer. Heterogeneous solid state electrodes are frequently known after their inventor E. Pungor (9-11).

A listing of commercially available solid state specific ion electrodes is given in Appendix B.

Silver Halide Specific Ion Electrodes: In solid state electrodes of the silver halide type, the silver ion is the charge carrier and does not involve the diffusion of halide ions. There are three main types of silver halide solid state electrodes. The oldes type, developed by Pungor et. al. (9, 10, 11) is heterogeneous membranes composed of silver halide precipitated in silicone rubber matrix. The latest version of these electrode systems is composed partly of silver halide precipitate, incorporated into a silicone rubber matrix, and partly of compact silver halide.

Homogeneous solid state membrane electrodes offer better performance characteristics than the heterogeneous types. The membrane is made from a mixture of silver halide and silver sulfide. The silver sulfide, which is much less soluble than any of the silver halides, serves to increase the membrane conductivity without affecting the membrane potential. These membranes have been found to be more applicable for measurement of Cl^-, Br^-, I^- and CN^- ions. Main interfering ions are sulfides and thiocyanates.

The potential determining ion in these electrode systems is the Ag^+ and the Nernst relationship can be expressed as follows

$$E_m = \text{constant} + \frac{RT}{F} \ln [Ag^+] \qquad (14)$$

and since

$$[Ag^+] = \frac{K_{AgCl}}{[Cl^-]} \qquad (15)$$

Where K_{AgCl} is the silver chloride solubility product, then

$$E_m = [\text{constant} + \frac{RT}{F} \ln K_{AgCl}] - \frac{RT}{F} \ln [Cl^-] \qquad (16)$$

Of particular interest to water quality monitoring are the Cl^- and CN^- electrodes which are being used with considerable success.

Silver Sulfide Specific Ion Electrodes: These electrode systems rely on the use of highly conductive, sparingly soluble Ag_2S membranes. The most applicable types are those made of homogenous membranes of compressed pellets of Ag_2S supplied by Beckman, Orion, Corning, Philips and Coleman. These electrodes respond only to S^{2-}, Ag^+ and Hg^{2+} ions, and to a certain degree to Cn^-. Theoretically speaking, the sensitivity to sulfides should follow a Nernstian relationship, to very low detection limits of 10^{-20}M. In order to achieve low detection limits it is recommended to use plastic containers instead of glass vessels, since silver ions adsorb strongly on glass.

Similar to halide electrodes, the potential determining ion is the Ag^+ and the Nernst relationship can be expressed as follows

$$E_m = \text{constant} + \frac{RT}{F} \ln [Ag^+] \qquad (17)$$

and since

$$[Ag^+] = \left[\frac{K_{Ag_2S}}{[S^{2-}]}\right]^{0.5} \qquad (18)$$

where K_{Ag_2S} is silver sulfide solubility product, then

$$E_m = [\text{constant} + \frac{RT}{2F} \ln K_{Ag_2S}] - \frac{RT}{2F} \ln [S^{2-}] \qquad (18)$$

This electrode is also responsive to other forms of free sulfides, HS^- and H_2S, through the following equilibrium relationships

$$H_2S \underset{}{\overset{K_1}{\rightleftharpoons}} HS^- \overset{K_2}{\rightleftharpoons} H_2S \qquad (19)$$

where K_1 and K_2 are the first and second acidity constants for H_2S. Consequently, if the pH is known, the following equilibrium relationships can be used to calculate $[HS^-]$, $[H_2S]$ and total sulfides $[S_T]$,

$$\log [S_T] = [S^{2-}] + \log \frac{[H^+]^2}{K_1K_2} + \frac{[H^+]}{K_1} + 1 \qquad (20)$$

$$\log [H_2S] = \log [S^{2-}] + \log \frac{[H^+]^2}{K_1K_2} \qquad (21)$$

$$\log [HS^-] = \log [S^{2-}] + \log \frac{[H^+]}{K_1} \qquad (22)$$

Another type of the silver sulfide electrodes include those electrodes responsive to Cu^+, Pb^+ or Cd^+. The membrane is made of a pressed mixture of silver sulfide and divalent metal sulfides, e.g. PbS, CdS or CuS. The electrode is primarily responsive to Ag^+ activity which is dependent on the S^{2-} activity, which in turn depends on the activity of the divalent metal in solution according to the following equilibrium relationships

$$[Ag^+]\ [S^{2-}] = K_{Ag_2S} \qquad (23)$$

$$[M^{2+}]\ [S^{2-}] = K_{MS} \qquad (24)$$

from which

$$[Ag^+] = \left[\left(\frac{K_{Ag_2S}}{K_{MS}}\right) [M^{2+}]\right]^{0.5} \qquad (25)$$

Since

$$E_m = \text{const.} + \frac{RT}{F} \ln [Ag^+]$$

it follows that

$$E_m = \text{const.} + \frac{RT}{2F} \ln \frac{K_{Ag_2S}}{K_{MS}} + \frac{RT}{2F} \ln [M^{2+}] \qquad (26)$$

This electrode system is selective for M^{2+} provided that

$$(K_{MS}) >> (K_{Ag_2S})$$

and MS solubility is sufficiently smaller than the concentration of M^{2+} in the test solution. In acidic media H^+ may interfere. Nevertheless, the operating range is from 10^{-1}M to 10^{-5}M. The main interfering ions are Hg^{2+} and Ag^+ for the cupric ion electrode and Hg^{2+}, Ag^+ and Cu^{2+} for the cadmium ion electrode. The cupric ion electrode may lose its selectivity in presence of Cl^- according to the following reaction

$$Ag_2S + Cu^{2+} + 2Cl^- = 2AgCl + CuS \qquad (27)$$

In this case the electrode may lose its selectivity to the Cu^{2+} and gain sensitivity to Cl^-.

Lanthanum Trifluoride Electrodes: This electrode system is selective to F^- ions and utilizes a membrane made of single crystal of LaF_3 which has been doped with europium (12). The Nernstian response is as follows

$$E_m = \text{constant} - \frac{RT}{F} \ln [F^-] \qquad (28)$$

The operating range is between 1M to 10^{-6}M. At low pH values the electrode potential will decrease due to the formation of HF or HF_2^- ions. Aluminum ions form stable complexes with fluorides (AlF_6^{3-}) over a wide pH range. At high pH the OH^- interferes with the electrode's selectivity (13). The lanthanum trifluoride electrode finds increasing applications in monitoring fluoride ions in natural waters, and fluoridated water supplies (13, 14, 15).

b. Liquid Ion Exchange Specific Ion Electrodes:

The calcium electrode: Specific ion electrodes of this kind are based on liquid membranes, in which are dissolved electroneutral salts of the ion of interest and ion-exchanger. The membrane is formed in an insoluble solvent layer (15). A typical example of these electrodes is the calcium or the divalent cation (Ca^{2+} and Mg^{2+} or hardness) electrodes. The membrane in this electrode system is a solution of calcium dialkyl phosphate in dioctylphenyl phosphonate. The electrode exhibits a Nernestian response,

$$E_m = \text{constant} + \frac{RT}{2F} \ln \left[Ca^{2+}\right] \qquad (29)$$

The operative concentration range is 10^{-1}M to 10^{-5}M. The electrode shows a significant hydrogen ion sensitivity and is usableouly within the pH range 6-11. The calcium and hardness electrodes have been used by numerous investigators for water quality analysis (14, 15, 19). The application of the calcium electrode for water quality monitoring purposes is primarily limited by the lack of stability and potential drift of these electrodes.

The Nitrate Electrode: In this electrode system, the ion exchanger is methyltricapryl ammonium ion and the solvent is 1-deconol (16). The operative pH range is 4 to 7. Major interferences are HCO_3^-, Cl^-, SO_4^{2-} and NO_2^-. Similar to above mentioned calcium electrode, the nitrate electrode suffer from lack of stability and potential drift which limit its application for monitoring purposes. In addition, the electrode sensitivity to commonly present interfering ions, such as HCO_3^-, Cl^- and SO_4^{2-} cannot be neglected.

A listing of commercially available liquid-ion exchange electrodes is given in Appendix B.

c. Gas Sensitive Potentiometric Membrane Electrodes:

Electrode systems of this type are available for the measurement of CO_2, NH_3 and SO_2. The CO_2 electrode has been in use for over two decades (17, 18 19), while the NH_3 and SO_2 are recently developed.

These electrode systems utilize a gas permeable plastic membrane to separate a thin layer of an electrolyte solution from the test solution. The electrolyte solution layer is in direct contact with the sensor system, e.g. glass electrode. Measurement is based on allowing a soluble gas e.g. CO_2 in the test solution to permeate through the plastic membrane and partition itself between the inner electrolyte layer and the test solution. Subsequent changes in the pH of the inner electrolyte layer, as determined by a glass electrode, are directly proportional to CO_2 content in the test solution. The plastic membrane may be polyethylene, teflon or rubber silicone.

In the case of the CO_2 electrode, the pH of the electrolyte layer will be directly dependent on partial pressure of carbon dioxide across the plastic membrane. The inner electrolyte layer is made of a mixture of KCl and $NaHCO_3$ (17). The electrode response may be improved by adding carbonic anhydrase (1 mg per ml) to the inner electrolyte layer in order to accelerate the CO_2 solubility reaction. Potentiometric measurement in the electrolyte layer requires the use of a reference electrode, which is in electrolytic contact with the glass electrode. Different electrode designs are reported in the literature (17, 18).

IV ON LINE MONITORING WITH SAMPLE CONDITIONING

In view of the above discussion, it is apparent that certain electrode systems can only function appropriately within restricted pH range or in the absence of certain interferences. Consequently it seems imperative to modify the sample physicochemical characteristics prior to measurement. Under these conditions in-situ analysis is not possible. Sample conditioning includes (a) filtration, dialysis or maceration, (b) dissolution, digestion or extraction, or (c) reagent addition for pH control or masking of interferences.

This approach has been applied for on-line monitoring of drinking water quality (13, 14, 20). On-line monitoring of continuous sample stream or discrete samples were made for the measurement of (a) total and free fluorides using the lanthanum trifluoride electrode, (b) copper, lead and cadmium using differential anodic stripping voltammetric techniques, (c) alkalinity using pH glass electrodes and (c) nitrates and hardness using liquid-ion exchange specific ion electrodes.

V. CONCLUSIONS

In-situ analysis in which the sensor is placed directly in the environment to be measured offers an ideal approach for water quality monitoring. Nevertheless the application of in-situ monitoring techniques is limited to a few number of parameter for which there are available sensor systems. In addition the response of available sensors may be significantly influenced by water flow, temperature and a number of chemical and biological interferences which may prevail at the monitoring site. Recent developments in using pulse voltammetric techniques minimize the influence of these environmental factors on the application of oxygen membrane electrodes.

Recently developed specific ion electrodes offer the opportunity for monitoring a variety of anions and cations. Solid state specific ion electrodes have been found to be more applicable for water quality monitoring than liquid ion exchange electrodes. In most applications sample conditioning may be required to maintain a given pH range or mask certain interferences.

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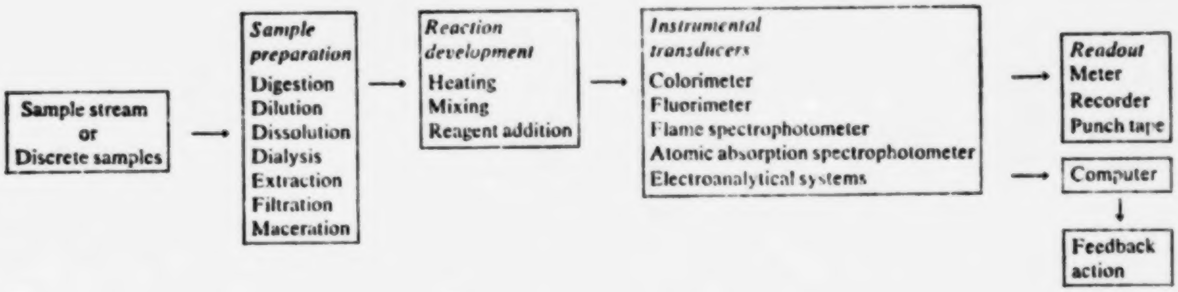
APPENDIX A

CONTINUOUS MONITORING BY AUTOMATED CHEMICAL SYSTEMS

(Technicon Instruments Corporation
Tarrytown, New York 10591)

I - BASIC OPERATIONS



II - PARAMETERS FOR WHICH AUTOMATED PROCEDURES ARE AVAILABLE

- Acidity (total)
- Alkalinity
- Aluminum
- Ammonia
- Arsenic
- Boron
- Bromide
- Cadmium
- Calcium
- Carbon dioxide
- Chloride
- Chlorine
- Chlorine demand
- Chlorine dioxide
- Chromium
- Cobalt
- COD (see oxygen, chemical)
- Copper
- Cyanide
- Fluoride
- Hardness
- Iodide
- Iron
- Lead
- Lithium
- Magnesium
- Manganese
- Mercury
- Nickel
- Nitrogen (Kjeldahl)
- Nitrates
- Nitrite
- Nitrogen (organic)
- Oxygen (dissolved)
- Oxygen demand (chemical)
- pH
- Phenols
- Phosphate
- Potassium
- Selenium
- Silica
- Silver
- Sodium
- Specific conductance
- Strontium
- Sulfate
- Sulfide
- Sulfite
- Surfactants
- Synthetic detergents
- Temperature
- Turbidity
- Zinc

APPENDIX-B

COMMERCIALLY AVAILABLE SPECIFIC ION ELECTRODES

I - SOLID STATE ELECTRODES

Beckman Solid State Membrane Electrodes

Addresses: 2500. Harbor Boulevard, Fullerton, Calif., 92634, U.S.A. (P.O. Box 1, Glenrothes, Fife, Scotland).

Ion	*Model*	*Molar Range*	*pH Range*	*Resistance (Megohms)*	*Response Time (Seconds)**	*Principal Interferants*
F^-	39600	$10^0 \rightarrow 10^{-6}$	$0 \rightarrow 13$†	< 5	< 3	OH^-
Cl^-	39604	$10^0 \rightarrow 5 \times 10^{-5}$	$0 \rightarrow 14$	< 1	< 2	Br^-; I^-; S^{2-} and CN^-
Br^-	39602	$10^0 \rightarrow 10^{-7}$	$0 \rightarrow 14$	< 1	< 2	I^-; S^{2-} and CN^-
I^-	39606	$10^0 \rightarrow 10^{-8}$	$0 \rightarrow 14$	$< 0{\cdot}25$	< 3	S^2
S^{2-}	39610	$10^0 \rightarrow 10^{-8}$	$0 \rightarrow 14$	$< 0{\cdot}25$	< 3	
Cu^{2+}	39612‡	10^{-8} (lower limit)	$0 \rightarrow 14$			Ag^+ and Hg^{2+}

Operative temperature range (°C) : $-5 \rightarrow 100$.

Overall size, length × diameter, (cm): $12{\cdot}8 \times 1{\cdot}25$.

* Defined as the time required to obtain a 90 per cent response to a stepchange from $10^{-4} \rightarrow 10^{-3}$ M concentration in a stirred solution. Will also depend on concentration and viscosity of samples. For the copper electrode up to several minutes may be required.

† At 10^{-1} M fluoride.

‡ Like the Coleman solid state electrodes contains no internal filling solution.

Orion 94 and 96 Series Solid State Specific Ion Electrodes

Addresses: 11 Blackstone St., Cambridge, Mass., 02139, U.S.A. (E.I.L., Richmond, Surrey) UK.

Ion	*Model*	*Total Molar Concentration Range**	*pH Range*†	*Resistance (Megohms)*	*Membrane Material*	*Principal Interferant Ions*
CNS^-	94-58	$10^0 \rightarrow 10^{-6}$	$0 \rightarrow 14$		$AgSCN + Ag_2S$	S^{2-}, Hg^{2+} and Cu^{2+} must be absent
CN^-	94-06	$10^{-2} \rightarrow 10^{-6}$	$3 \rightarrow 14$	< 30	$AgI + Ag_2S$	S^{2-} must be absent
F^-/La^{3+}	94-09	$10^0 \rightarrow 10^{-6}$	$0 \rightarrow 11$	< 1	$LaF_3 + Eu$‡	OH^- only interference
F^-/La^{3+}	96-09	$10^0 \rightarrow 10^{-6}$	$0 \rightarrow 11$	< 30	$LaF_3 + Eu$‡	
Na^+	94-11	$10^0 \rightarrow 10^{-6}$	$3 \rightarrow 12$	< 200		Ag^+
Cl^-	94-17	$10^0 \rightarrow 5 \times 10^{-5}$	$0 \rightarrow 13$	< 30	$AgCl + Ag_2S$	S^{2-} must be absent
Cl^-	96-17	$10^0 \rightarrow 5 \times 10^{-5}$	$0 \rightarrow 13$	< 30	$AgCl + Ag_2S$	
Br^-	94-35	$10^0 \rightarrow 5 \times 10^{-6}$	$0 \rightarrow 14$	< 10	$AgBr + Ag_2S$	S^{2-} must be absent
I^-	94-53	$10^0 \rightarrow 5 \times 10^{-8}$	$0 \rightarrow 14$	$1 \rightarrow 5$	$AgI + Ag_2S$	S^{2-} must be absent
S^{2-}	94-16	$10^0 \rightarrow 10^{-7}$	$0 \rightarrow 14$	< 1	Ag_2S	None as far as examined
Ag^+		$10^0 \rightarrow 10^{-7}$	$0 \rightarrow 14$		Ag_2S	Hg^{2+} must be absent
Cu^{2+}	94-29	$10^0 \rightarrow 10^{-7}$	$0 \rightarrow 14$	< 1	$Ag_2S + CuS$	S^{2-}, Ag^+ and Hg^{2+} must be absent
Cd^{2+}	94-48	$10^0 \rightarrow 10^{-7}$	$1 \rightarrow 14$	< 1	$Ag_2S + CdS$	Ag^+, Hg^{2+} and Cu^{2+} must be absent
Pb^{2+}	94-82	$10^0 \rightarrow 10^{-7}$	$2 \rightarrow 14$	< 1	$Ag_2S + PbS$	Ag^+, Hg^{2+} and Cu^{2+} must be absent

II - LIQUID ION EXCHANGE ELECTRODES

Some Corning Liquid Ion Selective Electrodes
Addresses: Corning Glass International, Medfield, Mass., 02052, U.S.A. (3 Cork St., London W.1)
(EEL, Hallstead, Essex)

Ion	*Model Number*	*Working Concentration Range*	*Operating pH Range*	*Temperature Range (°C)*	*Principal Interferants ($K_{MN} > 1$)*
Cl^-	476131	10^{-1}–10^{-5} M NaCl	1–12 in 10^{-1} M NaCl	10–50	$I^- > ClO_4^- > NO_3^- = Br^-$
NO_3^-	476134	10^0–10^{-5} M KNO_3	2·5–10 in 10^{-2} M KNO_3	0–50	$ClO_4^- > I^-$
Ca^{2+}	476041	10^0–10^{-5} M $CaCl_2$	5–10 in 10^{-2} M $CaCl_2$	10–60	None given
$Ca^{2+} - Mg^{2+}$	476235	10^0–10^{-5} M as Ca^{2+}	5–10 in 10^{-2} M $CaCl_2$	10–60	$(Ba^{2+} = Sr^{2+} > Ni^{2+} = Ca^{2+} = Mg^{2+})$*

Overall size (length × diameter) cm : 12·3/12·7 × 1·58.
Lifetime : 10–15 days (where quoted) before recharging with specified liquid ion exchanger.
Time response (s) : Generally < 60 for solutions differing by not more than ten-fold concentration changes.
Resistance (Megohms) : 500 quoted nominally for Ca^{2+} and $Ca^{2+} - Mg^{2+}$ electrodes only.
Minimum sample size (ml) : 10 quoted for Ca^{2+} and $Ca^{2+} - Mg^{2+}$ electrodes only.
Storage : Upright in air for short periods.
Ion exchanger liquid removed for prolonged periods.

- **Merely listed as such without any selectivity values.**

Orion 92-Series Liquid Ion Exchange Membrane Electrodes
Addresses: 11 Blackstone Street, Cambridge, Mass., 02139, U.S.A. (E.I.L., Richmond, Surrey)

Ion	*Model*	*Molar Activity Range*	*pH Range*	*Resistance (Megohms)*	*Principal Interferants (where $K_{MN} > 1$)*	*Mobile Exchanger Site*†
Cl^-	92–17	10^{-1}–10^{-5}	2–11	<30	Br^-, I^-, NO_3^-, ClO_4^- and OH^-	NR_4^+
NO_3^-	92–07	10^{-1}–10^{-5}	2–12	<30	I^-, ClO_3^- and ClO_4^-	$[Ni(phen)_3]^{2+}$
BF_4^-	92–05	10^{-1}–10^{-5}	2–12	<30	I^-	
ClO_4^-	92–81	10^0–10^{-3}	4–10/11	<30	OH^-	
Cu^{2+}*	92–29	10^{-1}–10^{-5}	4–7	<30	Fe^{2+}	$R-S-CH_2-CO_2^-$
Pb^{2+}*	92–82	10^{-2}–10^{-5}	3·5–7·5	<10	Cu^{2+}	
Ca^{2+}	92–20	10^0–10^{-5}	5·5–11	<25	Zn^{2+} (But see Table 2)	$(AlkylO)_2PO_2^-$
Divalent $Ca^{2+} - Mg^{2+}$	92–32	10^0–10^{-8}	5·5–11	<10	Zn^{2+}, Fe^{2+}, Ni^{2+} and Cu^{2+}	

Operative temperature range (°C): 0–50.
Overall size, length × diameter (cm): 14·9 × 1·7 (slightly larger dimensions were once quoted).
Minimum sample size (ml): 3–5 in 50 ml beaker: 0·3 in disposable Orion microsample dish.
Reproducibility: Drift, repeatability and response time characteristics are generally comparable with those of good quality pH electrodes.
Storage: Can be air-stored or immersed in appropriate standardized ion solution.
Electrode life: About 1–3 months without renewal of ion exchange liquid.
Dollar cost: 195

- Now withdrawn from Orion 1969 Research Guide. (Cat/961).

† Iron replaces nickel in the ion exchanger material for the ClO_4^- electrode.

III - HETEROGENEOU MEMBRANE ELECTRODES

Pungor-Radelkis Heterogeneous[*] Ion Selective Electrodes

Addresses
Protech, 40 High St., Rickmansworth, Herts (Advisory Services).
Simac Instruments Ltd., Bridgeway House, Bridge Way, Whitton, Middlesex (Technical Services).
Radelkis Electrochemical Instruments, Budapest 62, Hungary.

Ion	*Laboratory Model*[†]	*Molar Range*	*Maximum Resistance (Megohms)*[‡]	*Membrane Material*[‖]	*Principal Interferants*
Cl^-	OP-Cl-711[¶]	$10^{-1} \rightarrow 10^{-6}$	10	AgCl	S^{2-}; I^-; Br^-
Br^-	OP-Br-711[¶]	$10^{-1} \rightarrow 10^{-6}$	10	AgBr	S^{2-}; I^-
I^-	OP-I-711[¶]	$10^{-1} \rightarrow 10^{-7}$	10	AgI	S^{2-}
S^{2-}	OP-S-711[¶]	$10^{-1} \rightarrow 10^{-17}$	10	Ag_2S	
SO_4^{2-}	[**]	$10^{-1} \rightarrow 10^{-5}$		$BaSO_4$	
PO_4^{3-}	[**]	$10^{-1} \rightarrow 10^{-5}$		$BiPO_4$	
F^-	[**]			LaF_2-CaF_2	

Operative temperature range (°C) : 1/5 → 90
Overall dimension (length × diameter) cm : 11·5 × 1 for 711 Models.
Storage : Can be dry stored after a distilled water rinse.
Response time (s) : 15 → 60 (Up to 3 min quoted by Rechnitz and co-workers for some electrodes.) References 18 and 20.
Cost : $60

[*] The terms "homogeneous" and "heterogeneous" do not relate to the function, but to the composition of the electrodes. (Pungor, Reference 102).

[†] Industrial number OP-Ion-722. The OP-Ion-700 series carry side pin electrode connector plugs, while the OP-Ion-711 types are fitted with shielded cabling.

[‡] Pure silicone rubber $> 11 \times 10^{7}$ ohms.

[‖] Dispersed in silicone rubber matrix (50 wt per cent of silver salt).

[¶] These four electrodes may be used to assay Ag^+ ions after appropriate calibration but do not necessarily cover the same range.

[**] Not commercially available.

SECOND CONFERENCE ON ENVIRONMENTAL QUALITY SENSORS

NATIONAL ENVIRONMENTAL RESEARCH CENTER

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OCTOBER 10 and 11, 1973

CONTINUOUS MONITORING BY ION SELECTIVE ELECTRODES

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ABSTRACT

The use of ion selective electrodes for analyzing natural and treated water, as well as sewage and industrial wastes, has been increasing. Among the species that have been so determined are fluoride, chloride, sodium, ammonia, nitrate, calcium, total hardness, sulfide and cyanide. Although ion selective electrodes are potentiometric sensors and are thereby inherently adaptable for continuous monitoring, they must be used for this purpose with care because of such concerns as interferences, the need for pH adjustment and reference electrode instability.

The addition of a variety of pH buffers, salt solutions to control ionic strength, chelators to negate the effect of interfering metals, and ion indicators has been utilized to improve the capabilities of these measurements. However, in order to adapt such procedures for continuous analysis requires a more sophisticated monitoring system than simply the insertion of a sensing and reference electrode into a waste stream or natural water.

Such sophisticated monitors have been developed and are commercially available using ion selective electrodes as sensing devices, along with the addition of various chemicals to optimize the procedures. This paper discuss techniques that are utilized in such systems, giving as an example the cyanide monitor for analyzing waste waters.

Ion selective electrodes have been available commercially for several years (1). They have been used increasingly in analyzing water and waste water samples in both field and laboratory applications. Most of these uses, however, involve the analysis of single samples, rather than continuous monitoring. This paper will focus on their capabilities for the latter, discussing the problems and advantages in such use. Commercially available ion selective monitors will be described.

One of the most important characteristics of ion selective electrode systems relating to their use in continuous monitoring systems is their dc voltage output. This is shown in equation 1, relating the electrical potential read-out to the concentration, C_x, of ion "x", which is being sensed by the detecting electrode in conjunction with a reference electrode.

$$E(mv) = E_a + b \log (C_x \gamma_x + k_y C_y \gamma_y + \ldots.) \qquad (1)$$

The electrode inherently senses activity, rather than concentration, so that C_x must be multiplied by γ_x, the activity coefficient, in this equation. Also, the electrode, designed to sense ion "x", may sense other ions, "y" etc., so that their activities must also appear in equation 1 as additive terms, each being multiplied by its selectively constant k_y, etc. The coefficient b is primarily a function of temperature and the charge on the principal ion being sensed, while E_a is determined principally by the nature and construction of the reference and ion selective electrodes.

These variables in equation 1 must be carefully controlled or considered in designing an ion selective electrode monitoring system. In this regard, Table 1 lists the major factors affecting each of these variables. Since many ions being sensed are involved in equilibrium reactions, their concentrations C_x and C_y may be influenced by temperature, T, ionic strength, I, pH, and the presence of complexing agents. The sulfide and fluoride electrodes are good examples of such an effect of pH, since the weak acid forms HF, H_2S, and HS^- will be formed as the pH decreases. Similarly, fluoride may be readily complexed by aluminum(III) and thus its free ion, which is that sensed by the electrode, reduced in concentration. This was shown, for example, by Harwood(2), who compared the results of using EDTA and CDTA to chelate aluminum so as to minimize its complexation of fluoride. Table 2 presents Harwood's data comparing the relative efficiencies of these two chelating agents to improve the ability of the electrode to sense the total fluoride in the presence of varying amounts of added aluminum. It is apparent that CDTA is more effective, and that certainly, without the addition of such chelating agents, it is apparent that less fluoride would be detected than that present in the solution.

The preceding discussion indicates that T, I, pH and the presence of natural complexing agents can all effect the free concentration of the ion being sensed. These must be controlled, therefore, in a continuous monitoring system in order to accurately monitor concentration. This may be done by the addition of pH buffers, inert salt solution to control ionic strength, and chelating agents if the interfering ions are metals. Similarly, the temperature in the sensing system can be controlled. Also, the extent to which other ions may be sensed, as reflected by k_y, etc. must be considered. For the fluoride electrode, the only such ion in fresh waters that may interfere is hydroxide, but this is also readily controlled by pH (1). However, for other electrodes, such as calcium, it is necessary to consider the value of k_y for magnesium. Again, in natural, fresh waters the additive term for magnesium in equation 1 is unlikely to be significant (1).

E_a, as indicated in Table 1, can be affected by T, I, and the nature and construction of the ion selective and reference electrodes. Although temperature and ionic strength can be controlled in a monitoring system, there exists a serious likelihood of potential drift due to the inherent characteristics of the two electrodes in the system. It is, thus, desirable to choose electrodes with minimum drift characteristics, but also to standardize the system periodically.

Even when there is no complexation or equilibrium mechanism to affect the concentration of a free ion being sensed, variations in I, the ionic strength, can significantly affect the activity coefficient, γ_x, as indicated in Table 1. This effect on γ may be even more important than on E_a or C_x, but again may be readily controlled by addition of an inert salt solution to the continuous monitoring detection system.

Finally, the b variable of equation 1 is of considerable concern in a monitoring system. As indicated in Table 1, it is affected by temperature, the nature of the ion selective electrode, and the charge of the ion being sensed. For example, at 25°C the absolute value of b is typically 59 mv for a univalent ion electrode and 29.5 mv for a divalent one (1). However, b can vary, even when the system is selected and temperature is controlled, again indicating a need for calibration and standardization.

An ion selective electrode system for monitoring cyanide in waste waters has been described which increases the value of b and, therefore, results in a more sensitive system, since greater values of b cause a larger voltage change for a given change in concentration (3). This technique is of particular interest because it has been incorporated into a commercially available monitoring system. As discussed by Riseman (3), the conventional ion selective electrode system for cyanide at 25°C will produce a voltage E such that

$$E(mv) = E_a - 59 \log (CN^-) \qquad (2)$$

with (CN^-) referring to the cyanide concentration, assuming that ionic strength is maintained constant. However, cyanide may also be detected using an indicator technique with the silver-sulfide electrode whose potential follows the relationship

$$E(mv) = E_a + 59 \log (Ag^+) \qquad (3)$$

by adding a known concentration, C, of silver cyanide complex to the solution. The free silver ion concentration in solution will then be controlled by the variable cyanide concentration through the mechanism of the silver-cyanide complex ion equilibrium, with

$$Ag^+ = C/\beta_2(CN^-)^2 \qquad (4)$$

Substitution of equation 4 into equation 3 gives

$$E(mv) = E_a + 59 \log (C/\beta_2(CN^-)^2) \qquad (5)$$

which may then be arranged into the form

$$E(mv) = E'_a - 2x59 \log (CN^-) \qquad (6)$$

A comparison of equation 6, resulting from this indicator electrode technique, with equation 1 describing the conventional cyanide electrode system, indicates that the former has a slope, b, twice as large. This results in greater precision, but also, because the linear relationship between E and log (CN^-) continues at lower concentrations, the sensitivity of the indicator technique is a few ppb of cyanide, compared to about 50 ppb by the conventional cyanide electrode method (3).

It was also pointed out that if the waste water contains nickel or copper, it will be necessary to release the cyanide from their complexes by acid treatment with EDTA, followed by the addition of sodium hydroxide, with the formation of free cyanide and binding of the copper and nickel by EDTA, removing them as interferences. This indicator method for cyanide, incorporating the acid-heating pre-treatment and EDTA addition, followed by alkali and indicator complex, has been incorporated into a commercially available cyanide monitor (3). The block diagram of the chemical sensing system of this monitor, manufactured by Orion Research Incorporated, is shown in Figure 1 (3). The acidified EDTA (Reagent 1) is mixed with the sample at point A, heated at B, air bubbles removed from the stream at C, the stream then being pumped to D, where it is mixed with alkaline silver cyanide indicator (Reagent 2), and introduced with dynamic mixing into a thermostatted electrode chamber, F, containing the sensing and reference electrodes. The system also has provision for periodic introduction of a 1 ppm standard cyanide solution at G. Also of interest is the fact that, rather than using a conventional reference electrode, such as calomel, it uses a sodium electrode which is exposed to a constant and high concentration of sodium from the sodium hydroxide addition, thus reducing the instability that is often associated with reference electrode systems.

The techniques incorporated in this cyanide monitor are also represented in a range of several ion selective electrode monitoring systems manufactured and described by Orion Research Incorporated as their series 1000 (4). As with the cyanide monitoring system, they use reagent addition techniques to reduce electrode and method interferences and control ionic strength, and incorporate ion selective electrodes like sodium as reference electrodes to reduce potential drift. They also provide for filtration of the sample stream to remove suspended solids, and have temperature control and automatic periodic standardization. It is reported that drift of readings typically does not exceed 2 to 3% per 24 hours, and precision is better than ± 5% over four decades of concentration (4). These monitor systems have been designed to eliminate the variabilities and interferences that would otherwise reduce the applicability of ion selective electrodes as continuous monitors for water and waste water.

The systems currently available commercially as Orion series 1000 monitors are listed in Table 3 as examples of the types of monitors capable of analyzing water or wastewater (4). The concentration range for each monitor is also shown, as well as possible interferences and typical standardization concentrations. Typical specifications for the series as a whole are shown in Table 4 (4). Although these monitors have become available only recently, one early report on the use of the fluoride monitor of this series indicates that the various components performed well during test, the automatic calibration feature performed according to specifications, and there was little baseline drift (5).

There is little doubt that ion selective electrode technology will continue to improve, and that an increasing number of ions will be capable of being monitored by such electrodes. The monitors described above, as well as those available from other manufacturers, attest to this. Also new chemical techniques utilizing existing electrodes, such as the indicator method, will also increase their versatility. Such monitoring systems will provide a welcome addition to the range of techniques available for water and waste water analysis.

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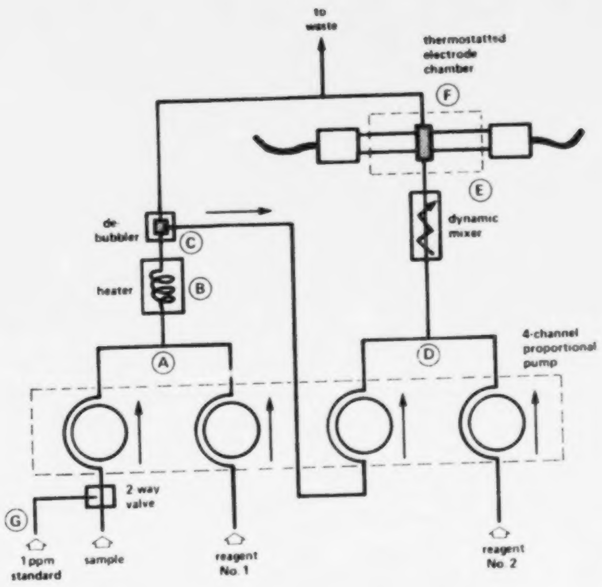


Figure 1. Block diagram of sensing system of typical Orion Model 1100 monitor (4).

Table 1. Effects on Electrical Potential For Ion Selective Electrode System

Variable	Major Effect on Variable
C_x, C_y....	T, I, pH, complexing agents
E_a	T, I, reference electrode, ions selective electrode
b	T, ion selective electrode, charge on ions sensed
$\gamma_x\gamma_x$	I
k_y....	Ion selective electrode, T, nature of ions sensed

Table 2. The Effect of EDTA and CDTA on Overcoming Aluminum Interference with Fluoride Analyses of 1 mg F/l, Using Different Aluminum Concentrations (2)

Aluminum concentration (mg/l)	0.2	0.4	0.7	1.0	2.0	3.0
Complexing agent	Fluoride result (mg F/l)					
EDTA	0.94	0.79	0.66	0.62	0.42	0.35
CDTA—1 g/l	0.99	0.99	0.98	0.98	0.96	0.95

Table 3. Currently Available (Sept. 1973) Orion Series 1000 Ion Selective Electrode Monitoring Systems

Species	Range (mg/l)	Interferences	Typical Standardization Concentration (mg/l)
NH_4^+/NH_3	1-100	Volatile amines	10
Cl^-	3.5-3550	None	10
OCl^-/Cl_2	0.05-100	Br^-, I^-	1
Cu^{++}	0.05-1000	None	Variable
CN^-	0.05-100	Au^{+3}, Ag^+	1
F^-	0.1-10	None	1
Hardness	0.01-100	$S^=$	Variable
NO_3^-	1-10,000	ClO_4^-, ClO_3^-	Variable

Table 4. Some Typical Specifications of Orion Series 1000 Ion Selective Electrode Monitoring Systems

Accuracy:	± 10 %
Precision:	Better than ±5%
Response Time:	99% response to change at inlet: 8 minutes 90% response to change at inlet: 6 minutes
Sample Supply:	100-1000 ml/min
Sample Temperature:	0°-60°C
Reagent Consumption:	0.22 ml/min
Stand. Sol'n Consumption:	50 ml/stand. cycle
Frequency of Automatic Standardization:	one/day
Size:	33 in high x 27 in wide x 14 in deep
Weight:	220 lb
Power Requirements:	115V, 60Hz, 100 watts

A REGIONAL WATER QUALITY MONITORING SYSTEM

RUSSELL H. SUSAG, PH.D., P.E.
MANAGER OF QUALITY CONTROL
METROPOLITAN SEWER BOARD OF THE TWIN CITIES AREA

PRESENTED AT THE
U. S. ENVIRONMENTAL PROTECTION AGENCY
SECOND CONFERENCE ON ENVIRONMENTAL QUALITY SENSORS
NATIONAL ENVIRONMENTAL RESEARCH CENTER
OCTOBER 10-11, 1973

INTRODUCTION

> "I often say that if you can measure that of which you speak or can express it by a number, you know something of your subject; but if you cannot measure it, your knowledge is meagre and unsatisfactory."
>
> Lord William Thomson Kelvin, 1824-1907

> "Maintenance of high water quality standards cannot be assured unless there is a stringent operating program with constant surveillance of river conditions and means to provide quick and appropriate ameliorative action. Even the most skilled and experienced sanitary engineer or hydrologist cannot determine the quality of water just by looking at it. All the latest scientific aids must be utilized to prevent pollution."
>
> Metropolitan Development Guide - Sanitary Sewer Section,
> Metropolitan Council of the Twin Cities Area
> January 22, 1970

The Metropolitan Sewer Board of the Twin Cities Area is a seven-county regional agency created by the 1969 Minnesota State Legislature "........ for the protection of the public health, safety, and welfare of the area, for the preservation and best use of waters and other natural resources of the state in the area, for the prevention, control and abatement of water pollution in the area, and for the efficient and economic collection, treatment and disposal of sewage ...." The Metropolitan Sewer Board provides wastewater treatment for 1.7 million residents of 90 communities that comprise 85% of the Minneapolis-St. Paul metropolitan area. Twenty-four wastewater treatment plants are operated, ranging in size and complexity from a 70,000 gpd two-stage stabilization pond-percolation system to a 220 mgd step aeration modification of the activated sludge process. Further, the Metropolitan Sewer Board will place into operation in November 1973 the first full-scale physical-chemical treatment plant, a 600,000 gpd treatment facility providing phosphorus and nitrogen removal in addition to BOD and SS removal.

When the Metropolitan Sewer Board began operation in 1970, the agency took over the operation of 33 wastewater treatment plants from individual communities and from sanitary sewer districts in the metropolitan area. At that time, there was very little, if any, coordination between the operation of these facilities. The primary consideration in location of these treatment plants was political boundaries and water quality suffered amid inefficiently operated facilities and counter charges of, "It's their fault". The Metropolitan Sewer Board, demonstrating a regional water management concept, is consolidating operations by phasing out overloaded and poorly located treatment facilities and diverting flow to regional facilities. The prime consideration now is the protection of the water resources of the area within the framework of efficient economic wastewater treatment rather than merely the treatment of each specific community's wastewater.

WATER QUALITY MONITORING

Uses for Data

There are three basic uses for water quality data obtained from a monitoring program. These are:

1. Planning. Water quality data is essential to the determination of location and degree of treatment for wastewater treatment facilities where the receiving water presents a water quality limiting situation.
2. Surveillance. The effectiveness of water pollution control facilities is measured by the determination of maintenance of water quality standards. Use of this data by a regulatory agency would provide the basis for enforcement action.
3. Operation Control. Wastewater treatment plant removal could be varied to meet the varying conditions of incoming receiving water quality in situations where removals in excess of secondary treatment are required.

Planning

The monitoring of the quality of the water resources of the Twin Cities Metropolitan Area on a routine basis dates back 47 years. In 1926, a program of river sampling was begun by the Minnesota State Department of Health to determine the quality of the Mississippi River and the impact of wastewater discharges from the cities of Minneapolis and St. Paul. This sampling program was taken over in 1927 by one of the predecessors to the Metropolitan Sewer Board, the Metropolitan Drainage Commission. A program of sampling and analyses at 16 stations over a 100 mile reach of the Mississippi River was conducted to get background material for the purpose of designing and locating a treatment plant for Minneapolis and St. Paul. Weekly samples were analyzed for the routine pollution measures of temperature, pH, turbidity, dissolved oxygen, BOD, and coliform organisms. The original Minneapolis-St. Paul (Metropolitan) treatment plant was placed into operation in 1938 and the sampling program initiated in 1926 was continued by the Minneapolis-St. Paul Sanitary District in order to monitor the effect of the institution of wastewater treatment on Mississippi River water quality.

Water quality standards have been changed twice since 1938 and the data generated from this sampling program have served as the design basis for plant expansion programs. The Minnesota Pollution Control Agency is in the process of further revising water quality standards and this background data is serving as a basis for load allocation studies. The Metropolitan Sewer Board as a regional agency can locate treatment works such as to provide the best protection of the water resources of the area and thus the Sewer Board is less governed by political boundaries than individual communities would be. Thus, a continuing water quality monitoring program is essential to a continuing planning program.

Surveillance

The Metropolitan Sewer Board is charged with the responsibility of maintaining the quality of the water resources of the area so as to allow for beneficial uses by the citizens of the area. In order to accomplish this, the Metropolitan Sewer Board is expected to carry on a program of water quality monitoring to demonstrate that, in fact, water quality standards are being maintained. From the standpoint of the operating agency, water quality monitoring from a surveillance standpoint has further value in allowing for the evaluation of the effectiveness of a water pollution control project. The requisite degree of treatment to meet water quality standards is most often determined from mathematical models that are based upon theoretical considerations or upon empirical relationships developed elsewhere. A water quality monitoring program to provide surveillance after the fact will allow for evaluating the tools used to predict requirements. Necessary modifications can be made so that future planning is effective.

The continuation of the sampling program, begun in 1926 on the Mississippi River, is an example of a water quality monitoring program begun for planning purposes that was continued for surveillance purposes. In addition, the Minneapolis-St. Paul Sanitary District instituted a program of automatic river water quality monitoring and telemetering of data to a central processing point in conjunction with a demonstration program for regulation of combined sewer overflows. Five automatic monitors with capability for sensing six parameters (temperature, pH, conductivity, dissolved oxygen, chloride, and oxidation-reduction potential) were sited on the Mississippi River to evaluate the effectiveness of a program of controlling combined sewer regulator overflows. These monitors were operated for a period of three years during the course of the demonstration program. Four of the five original monitors are being relocated to new sites that will be more compatible with the goals of an overall river monitoring program.

From the standpoint of a regulatory agency, water quality monitoring for surveillance purposes becomes an enforcement tool. The U. S. Environmental Protection Agency placed four automatic water quality monitors on the Mississippi and Minnesota Rivers to measure the progress of the metropolitan area in complying with the recommendations of an enforcement conference that was convened in 1965. The EPA has continued to operate three of these monitors to the present date. Most of the recommendations of the enforcement conference have since been accomplished and the EPA has loaned two of these monitors to the Metropolitan Sewer Board for use in the Sewer Board's water quality monitoring program. These monitors will be an important part of the Sewer Board's program because they were sited at points that are significant from the standpoint of water pollution control surveillance.

Operational Control

A third use for water quality monitoring data is that of providing information that can be used for decision making in operational control. As has been the case with most states, the State of Minnesota is in the process of revising water quality standards to conform with the requirements of the 1972 Amendments to the Federal Water Pollution Control Act. The upgrading of standards will, in many cases, necessitate the installation of tertiary treatment units or will require the initiation of operating practices that fall beyond the realm of what has been defined as secondary treatment. Tertiary treatment measures will not be required at all times to meet the upgraded water quality standards because seasonal variations in flow, temperature, and dissolved oxygen levels will result in variable receiving water assimilative capacities. During the low flow - high temperature river water conditions of August, a high degree of treatment may be required whereas secondary treatment would be adequate during the remainder of the year. Because of the high energy and resource consumptive nature of tertiary treatment practices, it would be desireable to limit their use to situations and conditions that warrant such extraordinary measures.

The Minnesota Pollution Control Agency has enacted, as a provision of its standards, the requirement for operation of all primary and secondary units of treatment works at their maximum capability. Variable operation of tertiary treatment units is allowed provided that water quality standards are met and that adequate monitoring capability is provided by the wastewater treatment agency. Thus, if chemical coagulation and filtration following secondary treatment were needed to provide the level of treatment necessary to meet standards during the infrequent low flow - high temperature critical periods, these tertiary units could be operated on an interim basis provided that monitoring is practiced such that the upstream flow and quality characteristics could be determined and transmitted to the operating agency so as to predict the necessary level of treatment to maintain the water quality standards. The use of a water quality monitoring program will allow for maximization of treatment plant capacity and optimization of the use of resources.

Any one of these uses of water quality data provides justification for a water quality monitoring program. It is felt that there will be continuing demands for data for all three uses. The requirements for eacn use are not all the same but are compatible and can be incorporated into a single monitoring program.

Practical Considerations in Siting Automatic Water Quality Monitors

Although theoretically monitors should be located at sites that provide the best information as to water quality and at the best points from the standpoint of monitoring impact of water pollution control facilities, in point of fact several other considerations govern. These are: accessibility, availability of utilities, security, and representativeness of sample. The following comments present Metropolitan Sewer Board experiences in locating and operating water quality monitors:

1. Accessibility. In most cases pumping restrictions require the monitor to be located near the water to be monitored. In some of the locations in the Sewer Board's program, the monitor has been placed on or adjacent to the flood plain, requiring periodic removal. One of our former locations was on the river side of a flood levee (constraints by political bodies and governmental agencies necessitated this location). Removal of this trailer monitor during high water required the use of a truck crane.
2. Availability of Utilities. Proximity to electric power and telephone service is a necessity. At the present time, two monitors are sited on dams in situations where it is not possible to telemeter data because of the absence of telephone lines. The data is being punched on paper tape by a digital recorder. (These monitors have as their primary purpose data gathering for surveillance uses.)
3. Security. Vandalism has proved to be a problem at some of our locations. At the EPA monitor on the Minnesota River, it was necessary that a pile cluster be driven in the river so that the intake could be located in the river. A navigational light on this pile cluster is frequently shot out by vandals.

   One of the Sewer Board's classic examples of vandalism occurred at a site where a trailer monitor was located on an old bridge abutment. This abutment was below the level of the existing bridge and vandals dropped rocks onto the top of the trailer monitor severing the electrical connection and the intake line. The last straw was when vandals broke into the trailer pulling all sensors, signal conditioners, and telemetering equipment out of the monitor.

In contrast, the Sewer Board had one trailer monitor on the Mississippi River sited along a very busy thoroughfare in plain view. This trailer has not been touched. Here is a case where security was gained not from isolation but rather from public exposure.

4. Representativeness of Sample. Location of the intake pump at a point in the river that provides a representative sample is a primary consideration. Fortunately, water intakes, bridges, docks, and dams generally provide representative sites as well as meeting the previously mentioned qualifications. Placement of pile clusters in rivers to allow for sampling in the main channel of a river can be an impediment to navigation and is frowned upon by the U. S. Corps of Engineers. One site, presently under consideration, is at a water supply intake structure. This site meets all qualifications but it will be necessary to forego data gathering during spring ice breakup conditions when the intake is closed.

METROPOLITAN SEWER BOARD WATER QUALITY MONITORING PROGRAM

The Metropolitan Sewer Board is in the process of developing a water quality monitoring network that can be used not only to generate information relative to maintenance of water quality standards but also to generate flow and quality data that can be used to regulate treatment process measures. In order to coordinate wastewater treatment operations with maintenance of water quality standards, it is necessary to obtain flow data as well. The Metropolitan Sewer Board has entered into a cooperative program with the U. S. Geological Survey to develop a water quantity-quality monitoring network. The USGS maintains four gauging stations on the three major rivers of the metropolitan area. Water quality monitors are being sited at three of the four major river gauge stations in addition to six other sites. The data will be transmitted over leased lines to a central data acquisition computer (Honeywell Model H-316) operated by the Metropolitan Sewer Board. In addition, the data will be tape punched on digital recorders so that a continuing record of variations in water quality can be maintained.

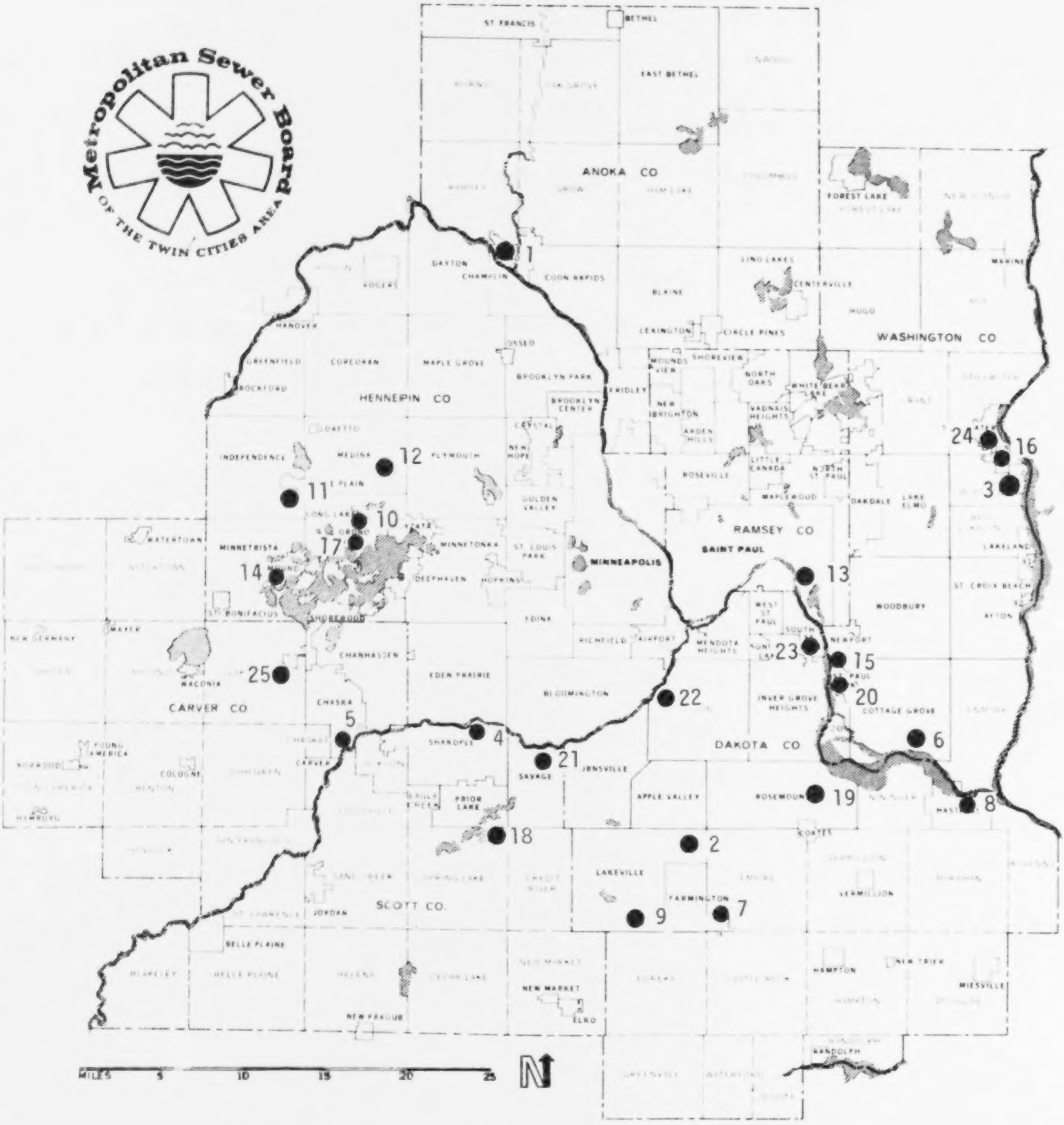
Analog data generated by the on-site flow meter or water quality sensor is converted at the site into a proportional time pulse signal of duration 0.2 to 13.33 seconds. The conversion is repeated every 15 seconds. Up to 15 flow meters or water quality sensors are transmitted over a single Bell System 3002 voice grade line to the central computer. Water quality values are converted to engineering units through the algorithm $V = K_1 + K_2 (T-.2)\uparrow N$. K_1, K_2 and N are assigned by the computer operator using a least squares fit program on data collected during site calibration. Sixty- 15 sec samples are collected every 15 min, screened for extreme values, reduced to a 15 min average value, and stored on a disc. The 15 min values are stored for the current operating day plus 3 days previous. An operator-initiated program reduces the 15 min data to quality mean, minimum value and time it occurred, maximum value and time it occurred. These reduced summaries are stored on the second or history disc for retrieval at any time. The history disc has capacity to store one year's data in the reduced form.

The automatic monitoring system will be composed of a mixture of new and existing equipment. The EPA has transferred, on loan, the operation of two of their water quality monitoring stations. These have been interfaced with the Metropolitan Sewer Board's data acquisition system and the EPA still maintains contact with these through a recorder. Weekly reports are sent to the local Water Quality Office of the EPA. Additionally, the Metropolitan Sewer Board has two operating water quality stations on the Mississippi River and one has been sited on the Minnesota River in cooperation with the USGS. Thus, at the present time the Metropolitan Sewer Board has a network of five water quality monitor stations, two on the Minnesota River defining a 36 mile river reach and three on the Mississippi River over a 22 mile reach. During this year, two additional monitors will be located upstream on the Mississippi River and a monitor will be placed on the St. Croix River. This will provide the Sewer Board with a network of eight monitor stations spanning 110 miles of the three major river systems in the Twin Cities Metropolitan Area. The EPA still maintains one monitor at the downstream extremity of the metropolitan area.

The original monitors of the Metropolitan Sewer Board are Fairchild monitors, which company was purchased by Automated Environmental Systems which then passed into the hands of Raytheon Corp. The EPA monitors are Schneider monitors and the new monitors that are being sited on a cooperative basis by the USGS and the Metropolitan Sewer Board are Ionics, Inc. monitors. Maintenance of these monitors is the responsibility of the Metropolitan Sewer Board. Technical support is provided for maintenance both by staff of the Metropolitan Sewer Board and by USGS staff.

The frequency of servicing of monitors varies by location. Those river locations that have the highest level of organic material require the most frequent servicing (up to twice a week). At some locations, during portions of the year, the water is of such outstanding clarity that only infrequent servicing is necessary. As a general rule, the monitors are serviced once a week. The pumping system is the principal continuing problem. As yet no substitute has been found for the Peerless submersible pump.

In addition to operating this monitoring program, the Metropolitan Sewer Board will be working with the USGS in developing procedures for data presentation such that the data will be meaningful to the general public as well as to the operating and regulatory agencies. The intent is to use this system to control operations such that water quality standards are maintained and such that this information can be disseminated and understood by all concerned. Automatic monitoring systems will provide the means by which there can be a maximum utilization of the financial, energy, and natural resources such that the desired water quality standards are maintained compatible with the designated beneficial uses of the water resources in the true sense of water pollution control.



METROPOLITAN SEWER BOARD

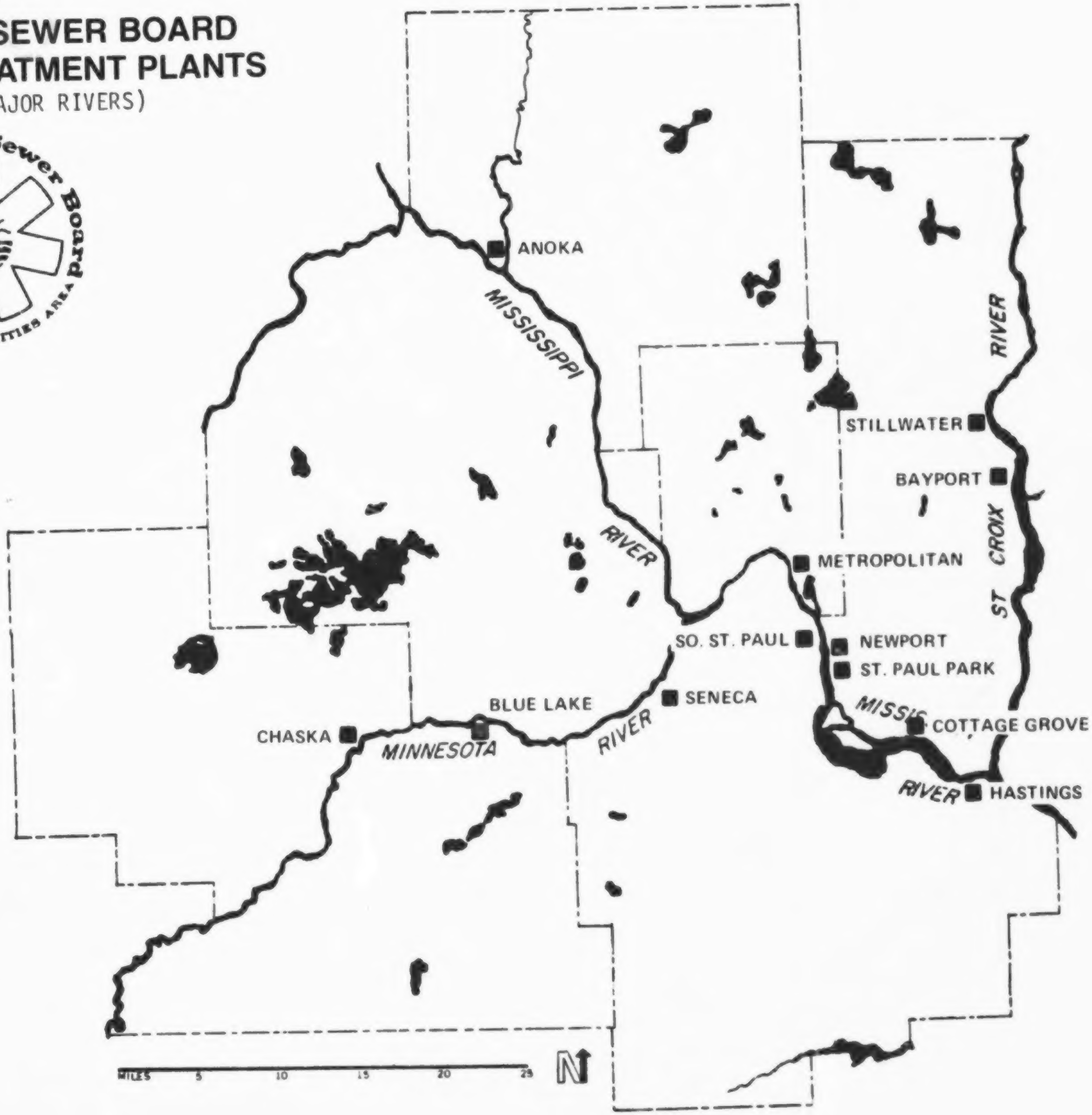
Wastewater Treatment Plants

● Treatment Plant in Operation During 1973

1 Anoka
2 Apple Valley
3 Bayport
4 Blue Lake
5 Chaska
6 Cottage Grove
7 Farmington
8 Hastings
9 Lakeville
10 Long Lake
11 Maple Plain
12 Medina
13 Metropolitan
14 Mound
15 Newport
16 Oak Park Heights
17 Orono
18 Prior Lake
19 Rosemount
20 St. Paul Park
21 Savage
22 Seneca
23 South St. Paul
24 Stillwater
25 Victoria

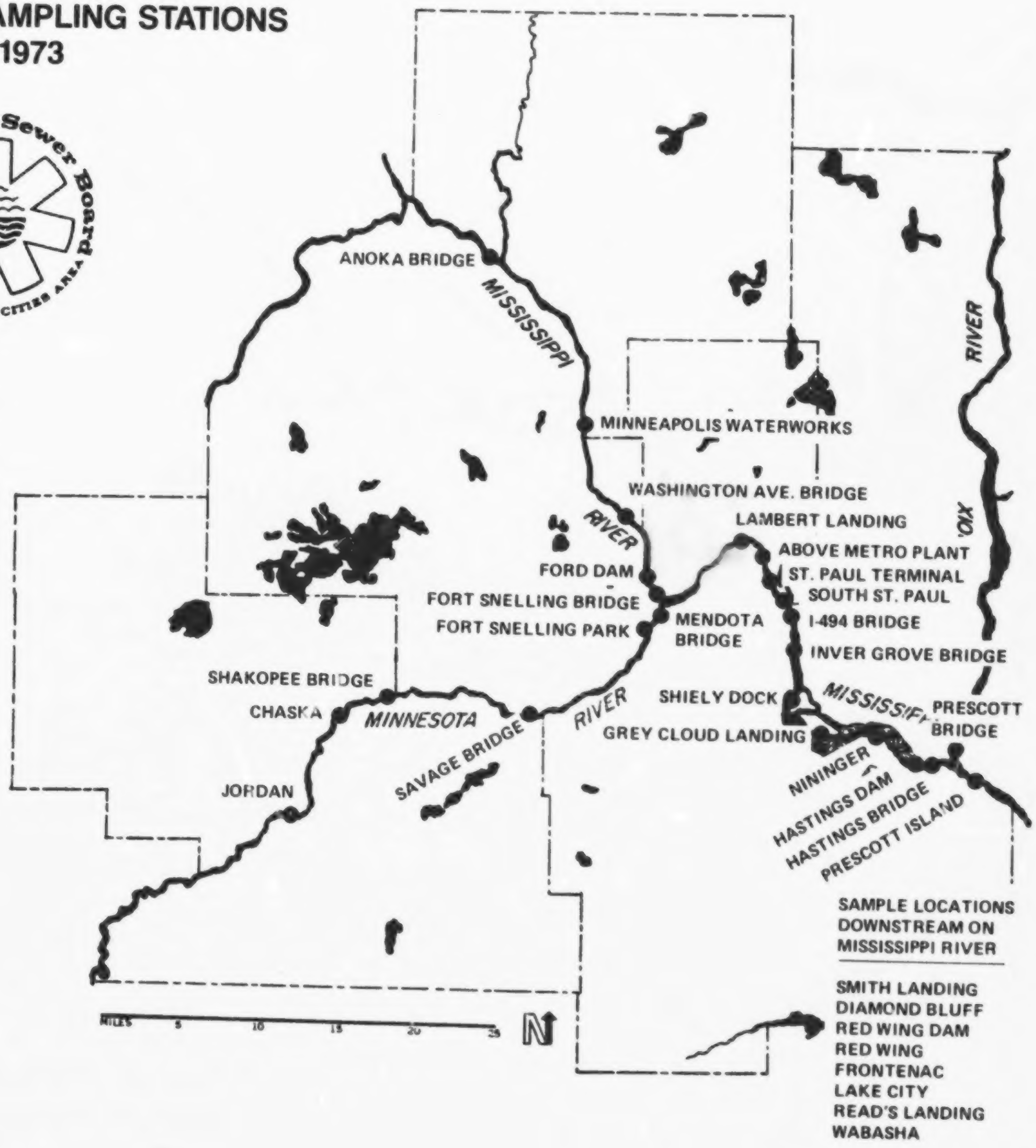
METROPOLITAN SEWER BOARD WASTEWATER TREATMENT PLANTS

(LOCATED ON MAJOR RIVERS)

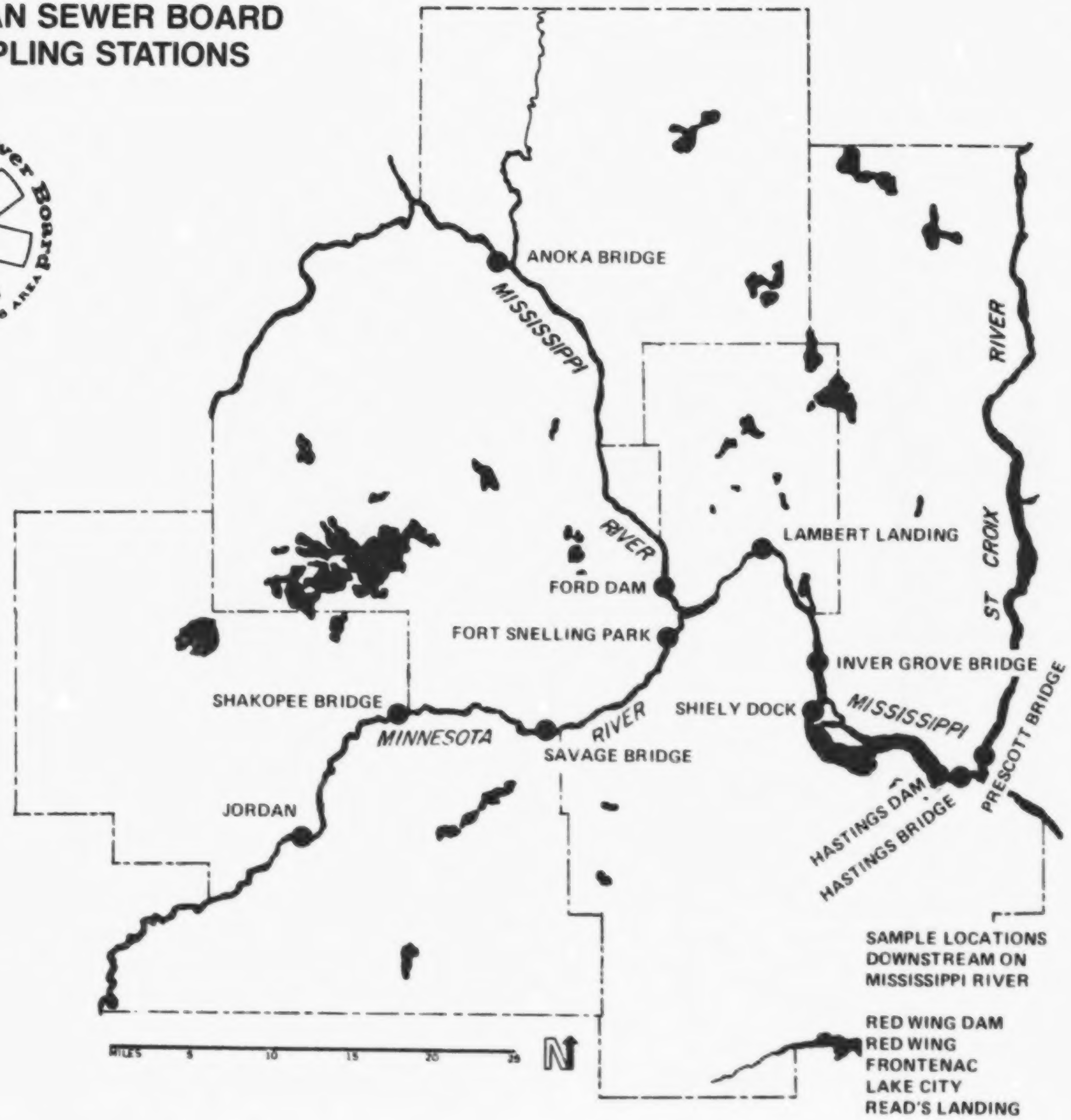


WATER QUALITY SAMPLING STATIONS
1927-1973

Metropolitan Sewer Board
OF THE TWIN CITIES AREA



PRESENT METROPOLITAN SEWER BOARD WATER QUALITY SAMPLING STATIONS



EXCERPTS

FROM

STATE OF MINNESOTA POLLUTION CONTROL AGENCY'S

REGULATION WPC 15

CRITERIA FOR THE CLASSIFICATION OF THE INTERSTATE WATERS OF THE STATE AND THE ESTABLISHMENT OF STANDARDS OF QUALITY AND PURITY

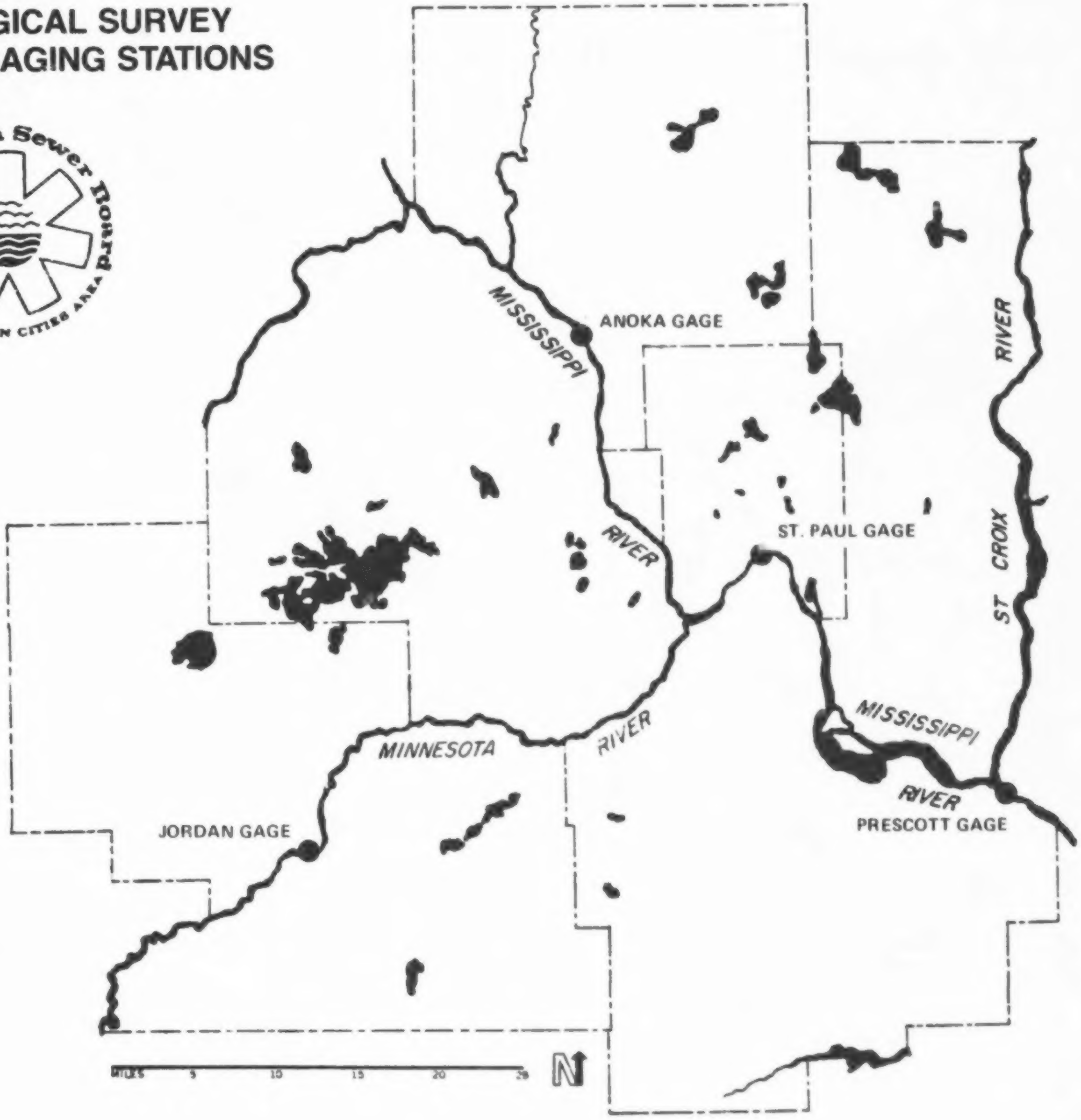
Section (c)(4) "The highest levels of water quality, ..., which are attainable in the interstate waters by continuous operation at their maximum capability *of all primary and secondary units* of treatment works or their equivalent .... shall be maintained in order to enhance conditions for the specified uses."

Section (c)(8) "........................... If treatment works are designed and constructed to meet the specified limits given above ($BOD_5 = 5$ mg/l, $SS = 5$ mg/l) for a continuous discharge, at the discretion of the Agency the operation of such works may allow for the effluent quality to vary between the limits specified above and in section (c)(6) ($BOD_5 = 25$ mg/l, $SS = 30$ mg/l), provided the water quality standards and all other requirements of the Agency and the U. S. Environmental Protection Agency are being met. *Such variability of operation must be based on adequate monitoring of the treatment works and the effluent and receiving waters* as specified by the Agency.

Emphasis added.

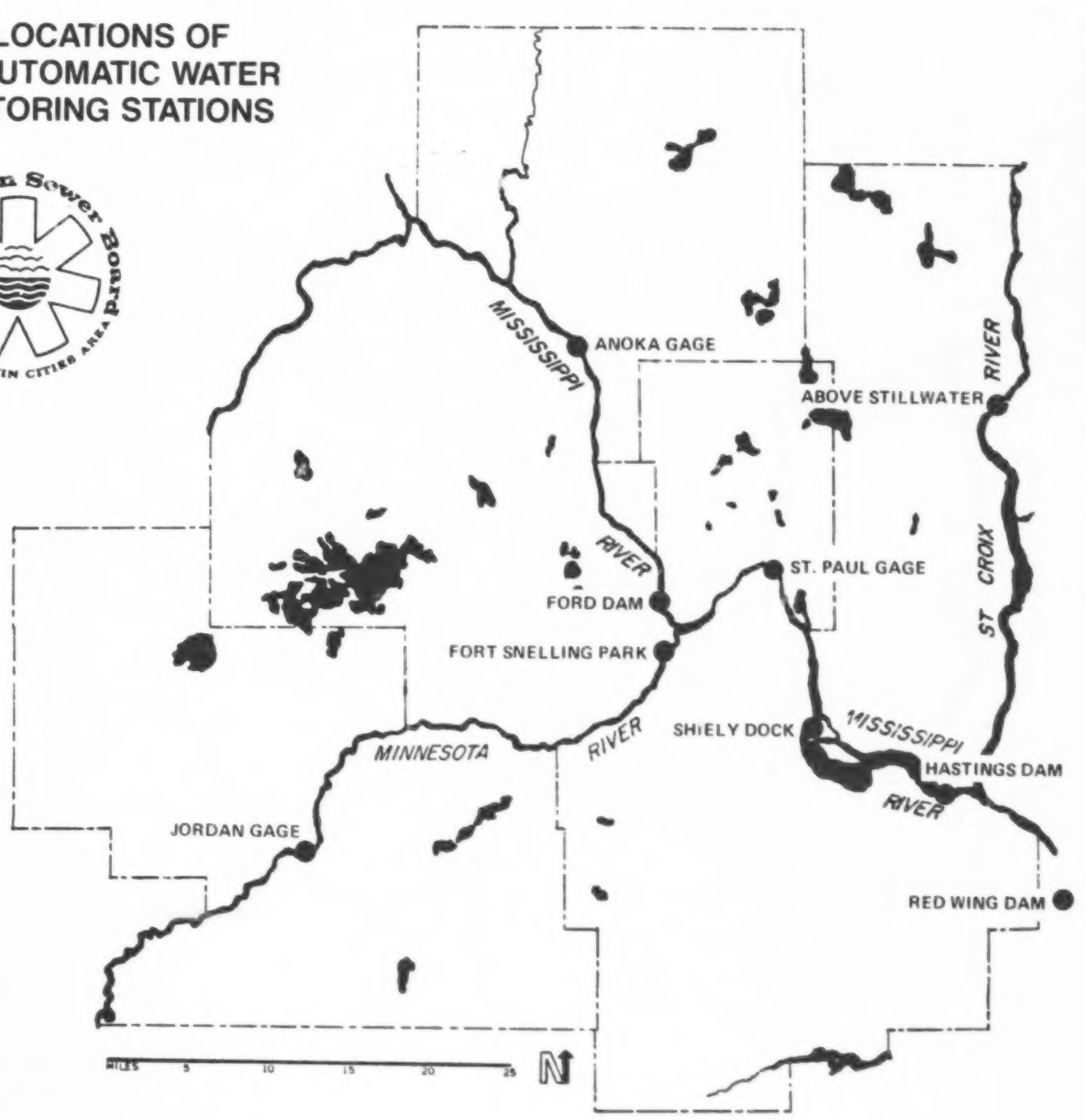
U.S. GEOLOGICAL SURVEY RIVER FLOW GAGING STATIONS

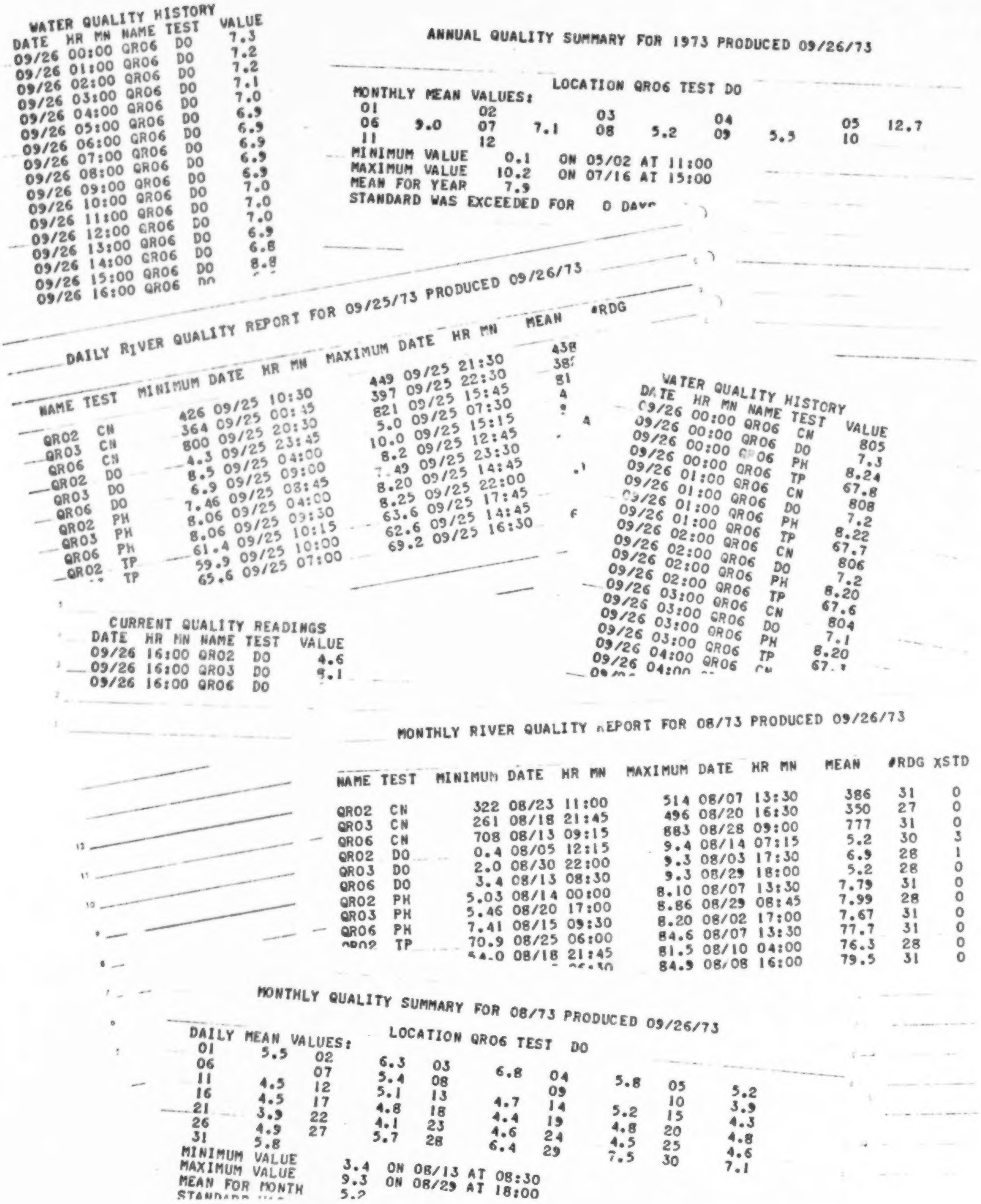
Metropolitan Sewer Board OF THE TWIN CITIES AREA



PROPOSED LOCATIONS OF CONTINUOUS AUTOMATIC WATER QUALITY MONITORING STATIONS

Metropolitan Sewer Board OF THE TWIN CITIES AREA





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WATER QUALITY HISTORY
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09/26 01:00 QR06  DO     7.2
09/26 02:00 QR06  DO     7.2
09/26 03:00 QR06  DO     7.1
09/26 04:00 QR06  DO     7.0
09/26 05:00 QR06  DO     6.9
09/26 06:00 QR06  DO     6.9
09/26 07:00 QR06  DO     6.9
09/26 08:00 QR06  DO     6.9
09/26 09:00 QR06  DO     6.9
09/26 10:00 QR06  DO     7.0
09/26 11:00 QR06  DO     7.0
09/26 12:00 QR06  DO     7.0
09/26 13:00 QR06  DO     6.9
09/26 14:00 QR06  DO     6.8
09/26 15:00 QR06  DO     8.8
09/26 16:00 QR06  DO
```

```
        ANNUAL QUALITY SUMMARY FOR 1973 PRODUCED 09/26/73

                        LOCATION QR06 TEST DO
MONTHLY MEAN VALUES:
 01              02              03              04              05   12.7
 06      9.0     07      7.1     08      5.2     09      5.5     10
 11              12
MINIMUM VALUE     0.1   ON 05/02 AT 11:00
MAXIMUM VALUE    10.2   ON 07/16 AT 15:00
MEAN FOR YEAR     7.9
STANDARD WAS EXCEEDED FOR   0 DAY
```

```
      DAILY RIVER QUALITY REPORT FOR 09/25/73 PRODUCED 09/26/73

NAME TEST  MINIMUM DATE  HR MN  MAXIMUM DATE  HR MN   MEAN   #RDG

QR02  CN       426 09/25 10:30      449 09/25 21:30    438
QR03  CN       364 09/25 00:45      397 09/25 22:30    38
QR06  CN       800 09/25 20:30      821 09/25 15:45    81
QR02  DO       4.3 09/25 23:45      5.0 09/25 07:30    4
QR03  DO       8.5 09/25 04:00     10.0 09/25 15:15
QR06  DO       6.9 09/25 09:00      8.2 09/25 12:45
QR02  PH      7.46 09/25 08:45     7.49 09/25 23:30
QR03  PH      8.06 09/25 04:00     8.20 09/25 14:45
QR06  PH      8.06 09/25 09:30     8.25 09/25 22:00
QR02  TP      61.4 09/25 10:15     63.6 09/25 17:45
      TP      59.9 09/25 10:00     62.6 09/25 14:45
              65.6 09/25 07:00     69.2 09/25 16:30
```

```
  CURRENT QUALITY READINGS
DATE  HR MN NAME TEST  VALUE
09/26 16:00 QR02  DO     4.6
09/26 16:00 QR03  DO     9.1
09/26 16:00 QR06  DO
```

```
  WATER QUALITY HISTORY
DATE  HR MN NAME TEST  VALUE
09/26 00:00 QR06  CN     805
09/26 00:00 QR06  DO     7.3
09/26 00:00 QR06  PH    8.24
09/26 00:00 QR06  TP    67.8
09/26 01:00 QR06  CN     808
09/26 01:00 QR06  DO     7.2
09/26 01:00 QR06  PH    8.22
09/26 01:00 QR06  TP    67.7
09/26 02:00 QR06  CN     806
09/26 02:00 QR06  DO     7.2
09/26 02:00 QR06  PH    8.20
09/26 02:00 QR06  TP    67.6
09/26 03:00 QR06  CN     804
09/26 03:00 QR06  DO     7.1
09/26 03:00 QR06  PH    8.20
09/26 03:00 QR06  TP    67.
09/26 04:00 QR06  CN
```

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          MONTHLY RIVER QUALITY REPORT FOR 08/73 PRODUCED 09/26/73

NAME TEST  MINIMUM DATE  HR MN  MAXIMUM DATE  HR MN   MEAN  #RDG XSTD

QR02  CN       322 08/23 11:00      514 08/07 13:30    386    31    0
QR03  CN       261 08/18 21:45      496 08/20 16:30    350    27    0
QR06  CN       708 08/13 09:15      883 08/28 09:00    777    31    0
QR02  DO       0.4 08/05 12:15      9.4 08/14 07:15    5.2    30    3
QR03  DO       2.0 08/30 22:00      9.3 08/03 17:30    6.9    28    1
QR06  DO       3.4 08/13 08:30      9.3 08/29 18:00    5.2    28    0
QR02  PH      5.03 08/14 00:00     8.10 08/07 13:30   7.79    31    0
QR03  PH      5.46 08/20 17:00     8.86 08/29 08:45   7.99    28    0
QR06  PH      7.41 08/15 09:30     8.20 08/02 17:00   7.67    31    0
QR02  TP      70.9 08/25 06:00     84.6 08/07 13:30   77.7    31    0
               4.0 08/18 21:45     81.5 08/10 04:00   76.3    28    0
                         06:30     84.9 08/08 16:00   79.5    31    0
```

```
        MONTHLY QUALITY SUMMARY FOR 08/73 PRODUCED 09/26/73
DAILY MEAN VALUES:          LOCATION QR06 TEST  DO
 01     5.5    02     6.3    03     6.8    04     5.8    05     5.2
 06            07     5.4    08            09            10     3.9
 11     4.5    12     5.1    13     4.7    14     5.2    15     4.3
 16     4.5    17     4.8    18     4.4    19     4.8    20     4.8
 21     3.9    22     4.1    23     4.6    24     4.5    25     4.6
 26     4.9    27     5.7    28     6.4    29     7.5    30     7.1
 31     5.8
MINIMUM VALUE         3.4   ON 08/13 AT 08:30
MAXIMUM VALUE         9.3   ON 08/29 AT 18:00
MEAN FOR MONTH        5.2
```

EXAMPLES OF COMPUTER PRINT-OUT FORMATS
OF
AUTOMATIC WATER QUALITY MONITORING DATA

WATER QUALITY MONITORING IN SOME EASTERN EUROPEAN COUNTRIES

by

Peter A. Krenkel* and Vladimir Novotny**

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** Assistant Professor of Civil Engineering, Marquette University, Milwaukee, Wisconsin

Introduction

With the new interest in water pollution control, it has become obvious that an adequate continuous and dependable water quality monitoring system will be mandatory in the future. The United States has probably been the leader in automatic water quality monitoring as exemplified by the ORSANCO system. In fact, other countries have looked towards the ORSANCO system as a model in order to formulate their own monitoring systems.

The problems of pollution control are compounded when a water passes an international boundary, thus making the need for continuous monitoring of water quality a requisite part of pollution control activities. It is interesting to note that while the United States has somewhat in the order of five per cent of the world's population, it uses, on an annual basis, more than 30 per cent of the world's resources. Americans do not recognize the fact that conditions throughout the world are not similar to those existing in the United States. For example, while most Americans do not concern themselves with the bacteriological safety of a drinking water supply, many countries in the world still have this fundamental problem, i.e., the possibility of contacting a disease through drinking water.

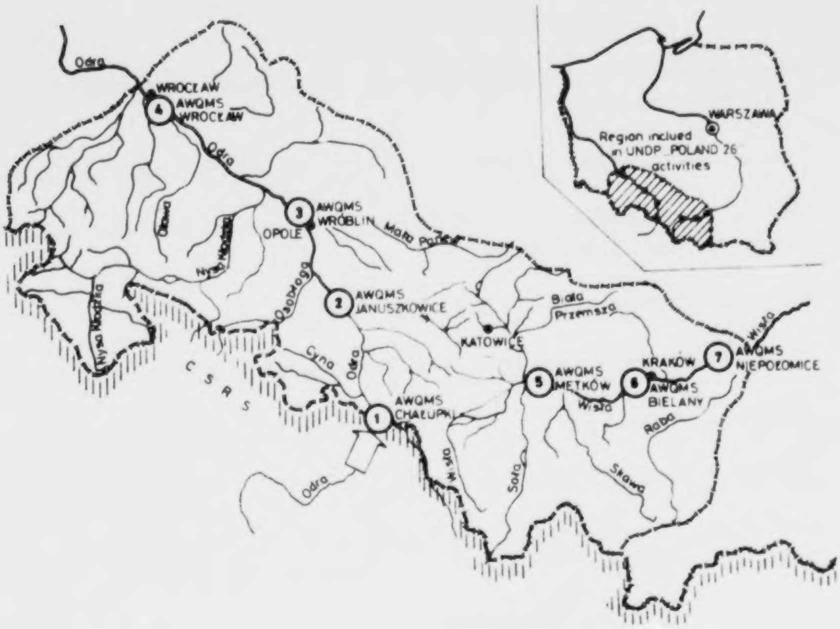
Because of the world wide implications of maintaining adequate water quality, the World Health Organization has instigated a program of support for certain countries through its United Nations Development Program (Special Fund endeavors). Eastern European countries involved in WHO projects of this type include Poland, Czechoslovakia, Romania and Hungary.

It is interesting to note that Hungary has a particular interest in water pollution control activities, inasmuch as over 90 per cent of their surface water supply crosses their borders from another country. Hungary is interested in a project that has been contemplated by WHO which would involve a comprehensive water management plan for the Danube River. The complexities of a water basin management plan in the United States are magnified on the Danube River, inasmuch as eight countries border the river and would have to cooperate in developing such a plan, should it be promulgated. These countries are Czechoslovakia, Romania, Hungary, Bulgaria, Russia, Austria, West Germany and Yugoslavia.

Most countries, upon learning of the success of the ORSANCO system in the United States, have indicated an interest in developing automatic water quality monitoring systems. Table I, which was taken from a study by the Economic Commission for Europe, shows the existing monitoring stations and plans for future stations of some of the countries involved. The country having the most experience with the installation and operation of automatic water quality monitoring stations at the present time is Poland, inasmuch as they have had some six years of support in this endeavor by the World Health Organization.

Because of the avid interest demonstrated in automatic water quality monitoring systems, the World Health Organization held a seminar on this topic in Cracow, Poland in the spring of 1971. This conference delineated the objectives, status and plans for automatic water quality monitoring systems by each country represented. The proceedings of this conference was published by Vanderbilt University in 1972 and contains much information that is not readily available in the English language (2).

Subsequent to several days of deliberation, the conferees arrived at the following objectives for automatic water quality monitoring stations.



GENERAL LOCATION OF AWQMS

FLORCZYK H.: RESEARCH AND STUDIES ON THE LOCATION OF AUTOMATIC WATER QUALITY MONITORING STATIONS - AWQMS

FIGURE 1

Compilation of actual and planned automatic water quality monitoring stations in various countries.

No	Country	Number of Stations existing or in the construction stage	 planned for the future
1	USA	205	1200
2	Sweden	12	30
3	Poland	7	53
4	GFR	6	75
5	Great Britain	4	240
6	Austria	1	-
7	Spain	-	10
8	Hungary	1	40 - 50
9	Holland	-	2

TABLE I

1. Identification of compliance and non-compliance with water quality standards
2. The establishment of water quality baselines and trends
3. The ascertainment of improvements in water quality resulting from abatement measures
4. The implementation of flow augmentation
5. The detection of emergency water quality problems
6. The determination of the "offender" in cases of waste spills
7. The detection of natural causes of abrupt water quality changes
8. The establishment of water quality relationships that would allow prediction of downstream quality conditions
9. The early warning of downstream users that adverse water quality conditions are approaching their water intakes

It is interesting to note that the common objectives as delineated by this meeting comprised of many European countries were quite similar to those of the United States, which only serves to demonstrate the world-wide need for common goals in terms of maintaining adequate water quality.

The Polish Automatic Quality Monitoring System

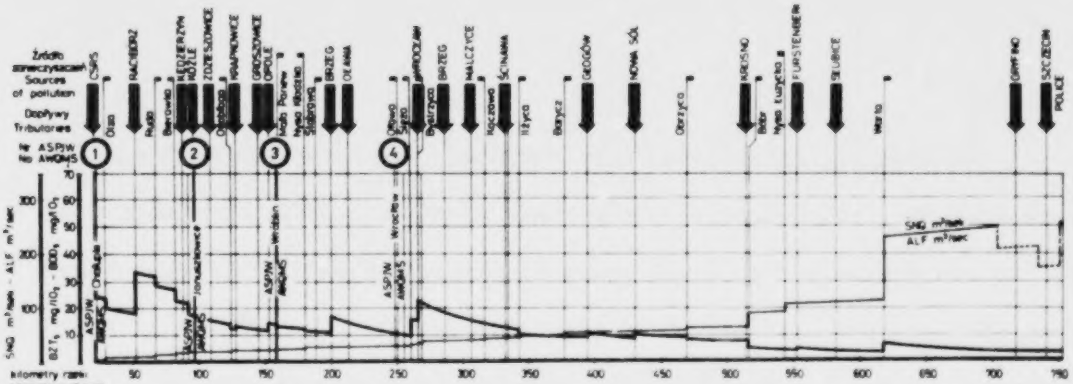
In order to demonstrate the procedures which have been instigated through World Health Organization projects, the Polish studies will be utilized. Through the WHO projects, Poland has installed seven automatic water quality monitoring stations throughout their country. These stations have been located on the two major river basins in Poland as shown on Figure 1. As will be shown subsequently, considerable care was given by the Polish workers in establishing the location of these stations and their procedures should be used as a guide for future endeavors of this type.

The stations established were equipped with Honeywell W-20 monitors, each measuring temperatures in the range from -5 to 40°C., conductivity in the range from 100 to 1,000 mhos, dissolved oxygen in the range from 0 to 15 parts per million, pH in the range from 1 to 14, oxidation reduction potential in the range ±500 mv , turbidity in the range from 0 to 500 ppm, chlorides in the range from 1 to 1,000 ppm, water level and solar radiation.

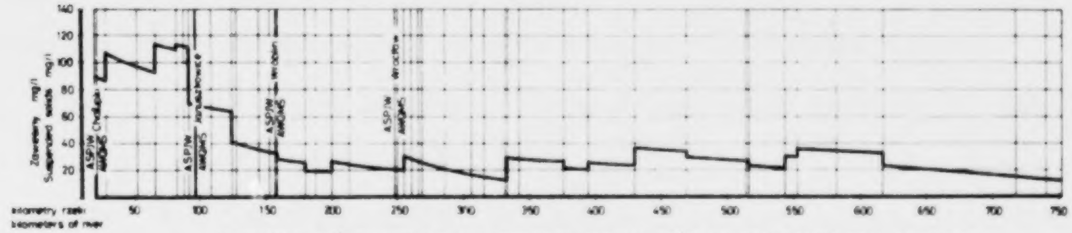
The two prime considerations with respect to location of the available number of automatic water quality monitors were to locate where the water was most important to the country's economy and to locate where irregularity of water quality parameters precluded manual sampling techniques. The general location was based on the state of pollution, the pollution characteristics, water utilization and the need and existence of waste water treatment plants.

In order to demonstrate the methodology that was used by the Polish workers in choosing the sites designated, the studies on the Odra River will be used, as described by Florcyk (3).

The first step in establishing the general location of the stations along the Odra River was to establish profiles of water quality parameters of interest. The detailed profiles developed are shown in Figures 2 through 7 which depict the changes in certain water quality parameters imposed on a profile of the Odra River. The parameters used on the Odra River were BOD, suspended solids, chlorides, phenols, sulphates, and dissolved solids. In addition to the profiles of the parameters, the location and designation of each waste load along the river profile is presented along with tributary rivers. It can be seen that four stations were chosen on the basis of these profiles as follows, Chalupki, Kozle-Januszkowice, Opole-Wroblin and Wroclaw.

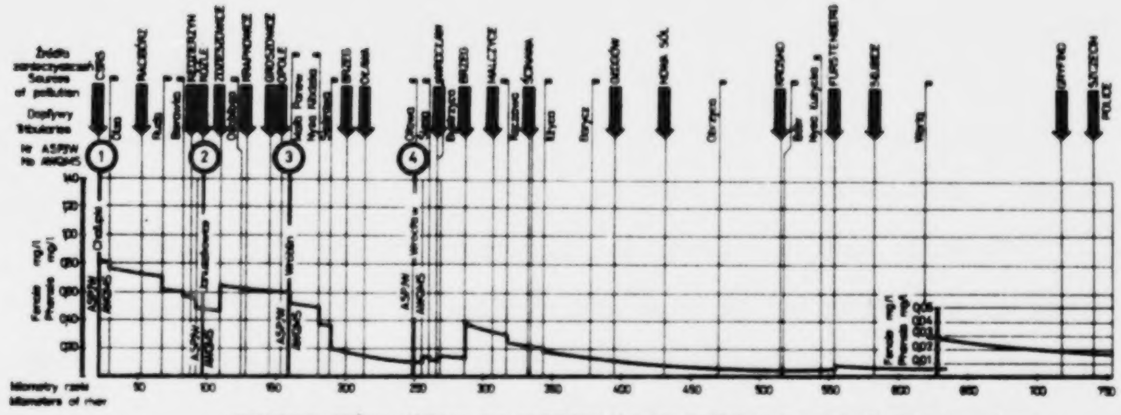


LOKALIZACJA OGÓLNA ASPJW NA TLE PRZEBIEGU KRZYWEJ BZT$_5$ WZDŁUŻ BIEGU RZEKI ODRY
GENERAL LOCATION OF AWQMS ON THE GROUND OF COURSE OF BOD$_5$ CURVE ALONG ODRA RIVER WATER COURSE

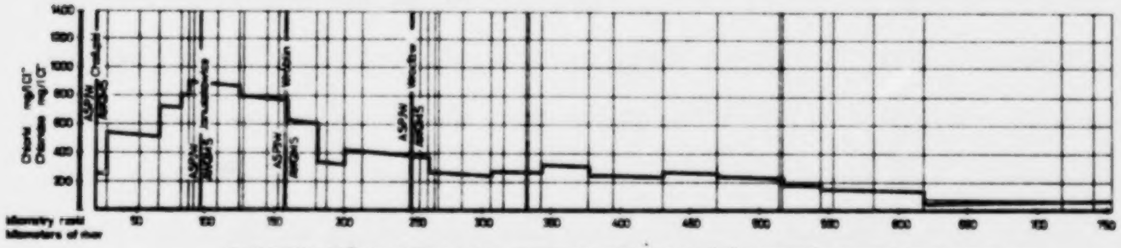


LOKALIZACJA OGÓLNA ASPJW NA TLE PRZEBIEGU KRZYWEJ ILOŚCI ZAWIESIN WZDŁUŻ BIEGU RZEKI ODRY
GENERAL LOCATION OF AWQMS ON THE GROUND OF COURSE OF SUSPENDED SOLIDS QUANTITIES CURVE ALONG ODRA RIVER WATER COURSE

FIGURES 2 & 3

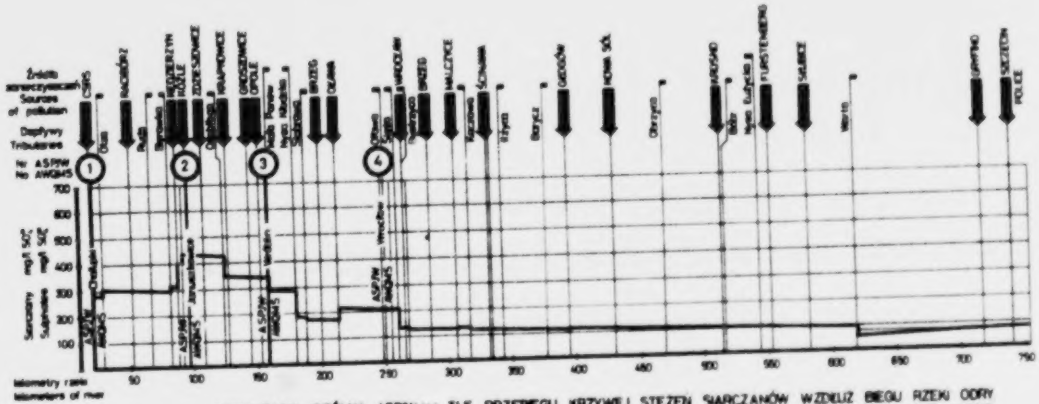


LOKALIZACJA OGÓLNA ASPJW NA TLE PRZEBIEGU KRZYWEJ STĘŻEŃ FENOLI WZDŁUŻ BIEGU RZEKI ODRY
GENERAL LOCATION OF AWQMS ON THE GROUND OF COURSE OF PHENOLS CONCENTRATIONS CURVE ALONG ODRA RIVER WATER COURSE

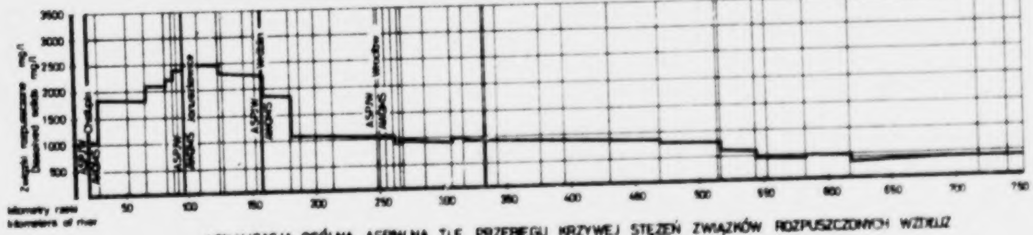


LOKALIZACJA OGÓLNA ASPJW NA TLE PRZEBIEGU KRZYWEJ STĘŻEŃ CHLORKÓW WZDŁUŻ BIEGU RZEKI ODRY
GENERAL LOCATION OF AWQMS ON THE GROUND OF COURSE OF CHLORIDES CONCENTRATIONS CURVE ALONG ODRA RIVER WATER COURSE

FIGURES 4 & 5



LOKALIZACJA OGÓLNA ASPIW NA TLE PRZEBIEGU KRZYWEJ STĘŻEŃ SIARCZANÓW WZDŁUŻ BIEGU RZEKI ODRY
GENERAL LOCATION OF AWQMS ON THE GROUND OF COURSE OF SULPHATES CONCENTRATIONS CURVE ALONG ODRA RIVER WATER COURSE

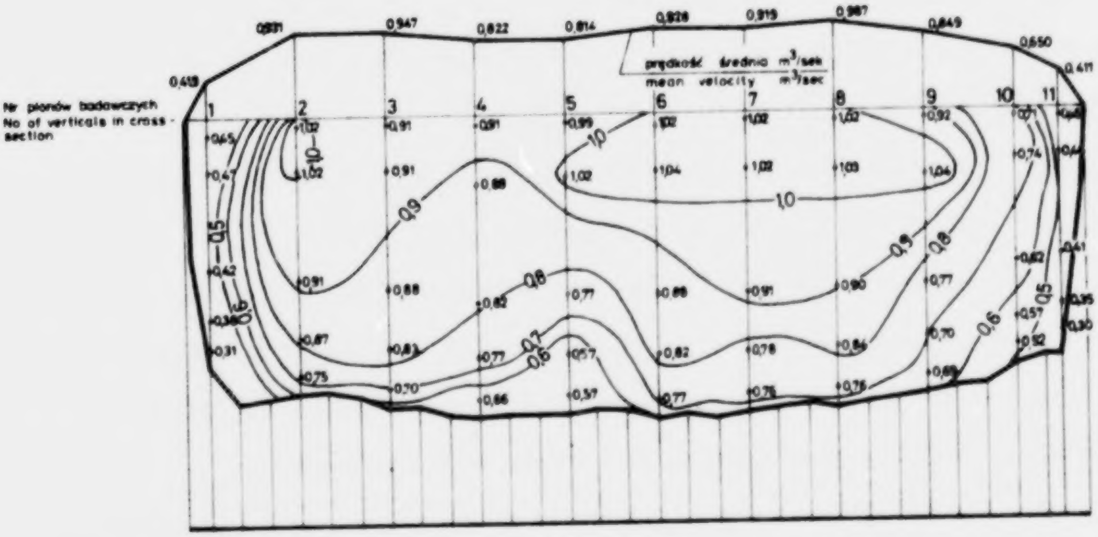


LOKALIZACJA OGÓLNA ASPIW NA TLE PRZEBIEGU KRZYWEJ STĘŻEŃ ZWIĄZKÓW ROZPUSZCZONYCH WZDŁUŻ BIEGU RZEKI ODRY
GENERAL LOCATION OF AWQMS ON THE GROUND OF COURSE OF DISSOLVED SOLIDS CONCENTRATIONS CURVE ALONG ODRA RIVER WATER COURSE

FIGURES 6 & 7

Przekrój pomiarowo - kontrolny
Monitoring cross - section
CHAŁUPKI

Rzeka
River
ODRA



ROZKŁAD PRĘDKOŚCI PRZEPŁYWU WODY W PRZEKROJU CHAŁUPKI NA RZECE ODRZE
DISTRIBUTION OF WATER FLOW VELOCITY IN CHAŁUPKI CROSS-SECTION, IN ODRA RIVER

FIGURE 8

The station at Chalupki was chosen because it shows the sources originating from Czechoslovakia, and in addition, demonstrates wide variation in water quality parameter characteristics. The station at Kozle-Januszkowice was chosen because of salinity problems introduced from Olza, Ruda, Bierawka, Klodnica, the Upper Silesia industrial region and the Rybnicki. In addition, a nitrogen plant in Kedzierzyn, the discharges from the city of Raciborz, and the location of the minimum point on the oxygen sag occurs in this location. It is anticipated that this station will control salinity discharges from various storage basins in the area in order to minimize chloride concentrations in the Odra River.

The station at Opole-Wroblin was chosen because of the upstream existence of the two largest sources of pollution on the Odra River, a paper mill in Krapowice and the city of Opole, other sources from the Opolski Silesia and the control of saline discharges from storage basins in the area.

The station at Wroclaw was chosen because it is the only city on the Odra River using Odra River water as a potable water supply, it has the largest industrial users of water, it was thought that the composition of these waters could be controlled, an upstream tannery exists in Brzey and finally, the monitoring station will allow insight into weir leveling in some 20 weir sites in 157 kilometers of impounded river.

Subsequent to choosing the general location of the monitoring station, specific sites were chosen using the criteria of reasonable field conditions, easy access by car, power connections, land implements and the possibility of providing constant supervision from a nearby existing facility.

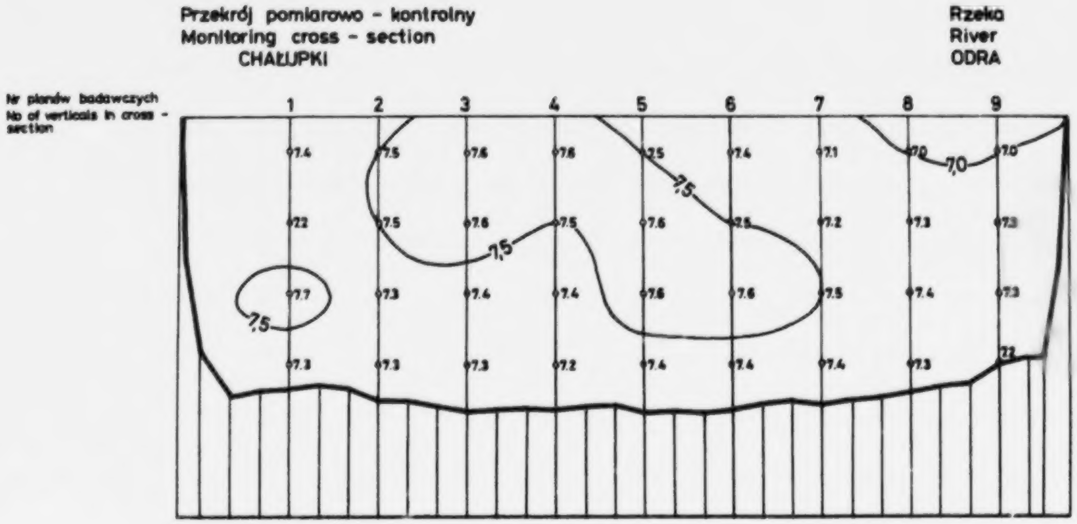
The chosen sites were then subjected to comprehensive cross-sectional analyses which included velocity, dissolved oxygen, clarified oxygen consumed, mixed oxygen consumed, chlorides and dissolved solids. If these profiles demonstrated uniform mixing, such that a representative sample would be obtained from the site, the site was designated as a good one. Cross-sections indicating non-homogeneity were rejected and studies made to determine where complete mixing occurred. Examples of the cross-sectional data taken on the Odra River are given in Figures 8 through 13, from which it can be observed that the parameters measured were reasonably homogeneous across the cross section, thus indicating a good monitoring site.

The data collection system consists of four basic sub-assemblies as shown on Figure 14. These include the measuring module, telemechanical equipment, transmission lines and terminal and registering equipment.

As previously indicated, the measuring module was a Honeywell W-20 instrument, the water being delivered by a screw-type pump. The major problem with this unit was with regards to maintaining the intake velocity the same as the river velocity. Temperatures are measured with thermistors, conductivity is measured with a measuring potentiometer with an internal temperature compensator, the dissolved oxygen is measured by a polaragraphic-type probe with a gold cathode and a silver anode and includes a temperature compensator, pH and ORP are measured with reference and measuring electrodes, the turbidity utilizes a reflectant methodology, the chlorides are measured similarly to ORP and pH, the flow level device uses a bourdon gauge and and solar radiation is measured using a eppley-type pyranometer.

Transmission is comprised of two systems, a radio link and a radio link plus telephone lines. The operating frequencies of the radio stations are each different in order to avoid interference.

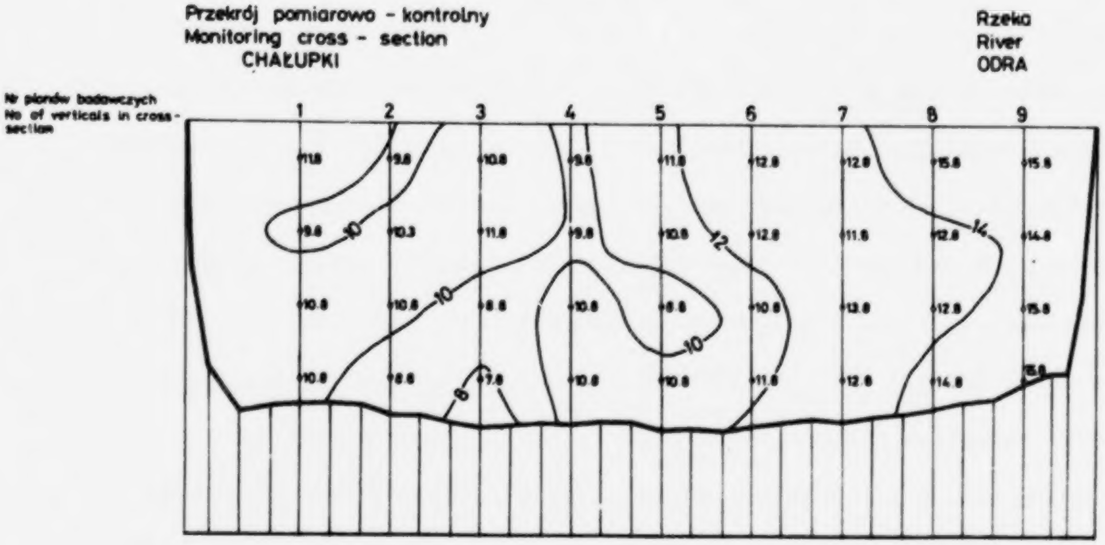
With regards to terminal and registering equipment, three methods were considered as follows: inscription on paper tape or on punched tape, periodical



ROZKŁAD ZAWARTOŚCI TLENU ROZPUSZCZONEGO W PRZEKROJU CHAŁUPKI NA RZECE ODRZE

DISTRIBUTION OF DISSOLVED OXYGEN CONCENTRATIONS IN CHAŁUPKI CROSS-SECTION, IN ODRA RIVER

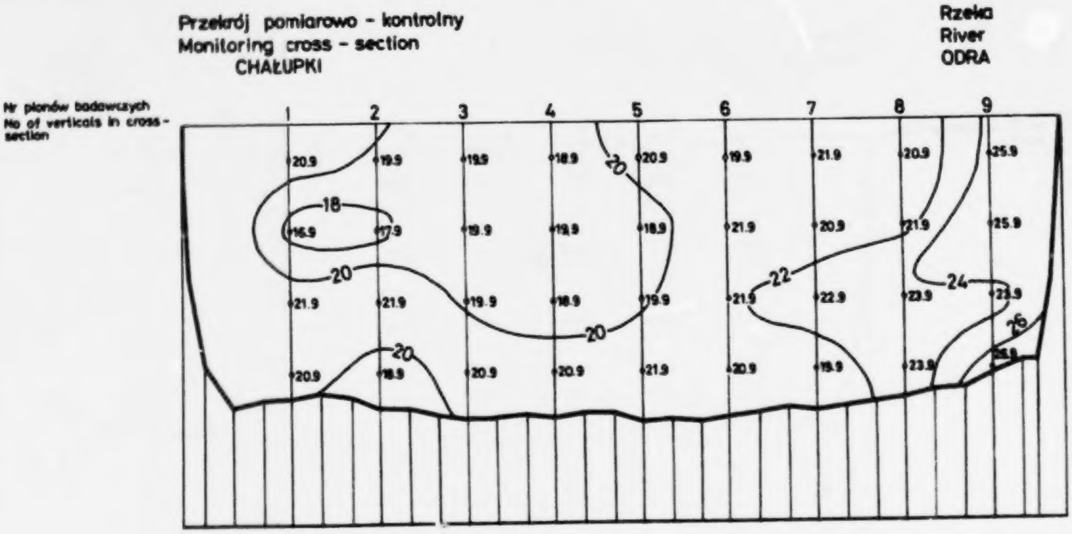
FIGURE 9



ROZKŁAD WARTOŚCI UTLENIALNOŚCI Z PRÓBEK SKLAROWANYCH W PRZEKROJU CHAŁUPKI NA RZECE ODRZE

DISTRIBUTION OF PERMANGANATE OXYGEN DEMAND VALUES FROM CLARIFIED SAMPLES IN CHAŁUPKI CROSS-SECTION, IN ODRA RIVER

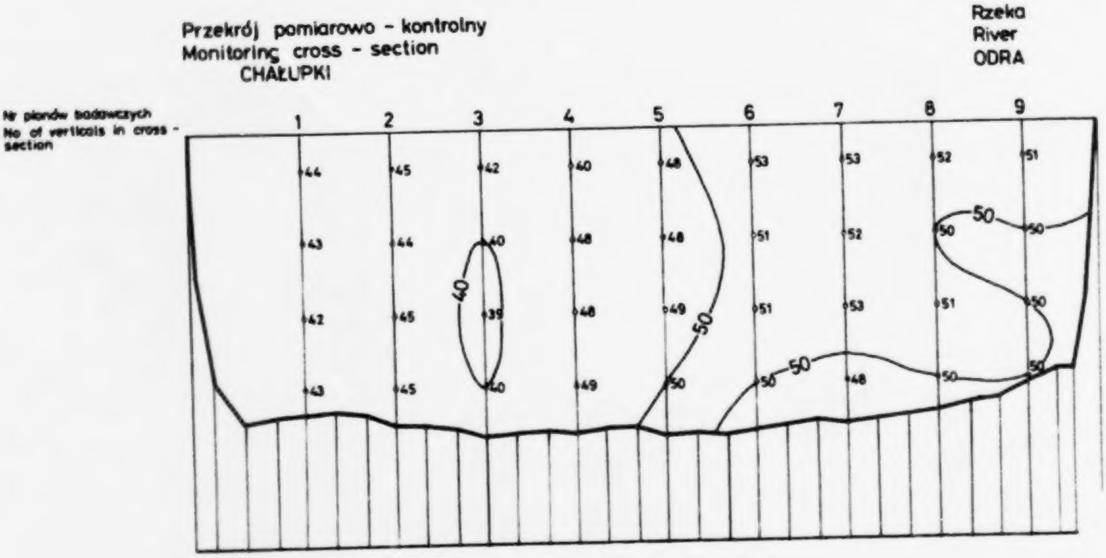
FIGURE 10



ROZKŁAD WARTOŚCI UTLENIALNOŚCI Z PRÓBEK SKŁÓCONYCH W PRZEKROJU CHAŁUPKI NA RZECE ODRZE

DISTRIBUTION OF PERMANGANATE OXYGEN DEMAND VALUES FROM MIXED SAMPLES IN CHAŁUPKI CROSS-SECTION, IN ODRA RIVER

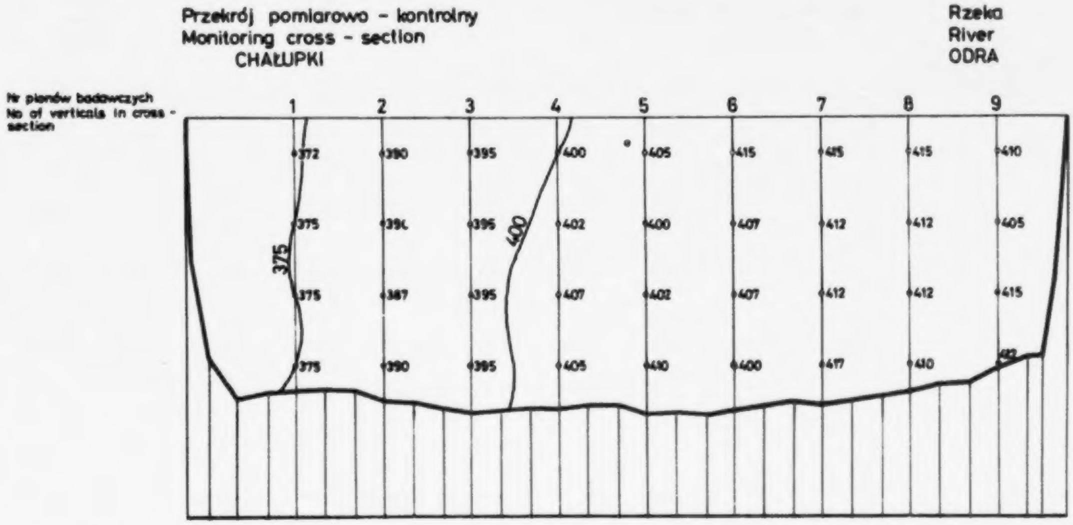
FIGURE 11



ROZKŁAD STĘŻEŃ CHLORKÓW W PRZEKROJU CHAŁUPKI NA RZECE ODRZE

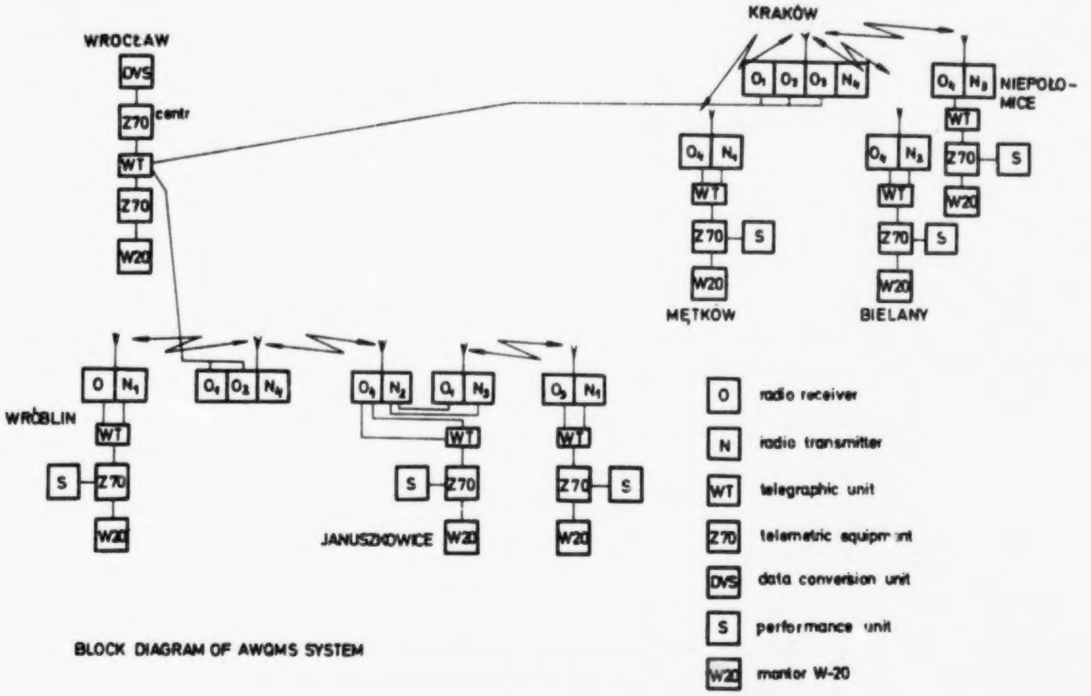
DISTRIBUTION OF CHLORIDES CONCENTRATIONS IN CHAŁUPKI CROSS-SECTION, IN ODRA RIVER

FIGURE 12



ROZKŁAD STĘŻEŃ ZWIĄZKÓW ROZPUSZCZONYCH W PRZEKROJU CHAŁUPKI NA RZECE ODRZE
DISTRIBUTION OF DISSOLVED SOLIDS CONCENTRATIONS IN CHAŁUPKI CROSS - SECTION, IN ODRA RIVER

FIGURE 13



BLOCK DIAGRAM OF AWQMS SYSTEM

FIGURE 14

inquiry and recording by teletype, and a complete data processing set which would compute the necessary routines with the aid of a computer. The option chosen was periodical inquiry and recording by teletype.

The data processing equipment performs the following operations:

1. Receiving 102 messages and 89 measured values from the memory circuits of the telemetering systems and processing them according to a given program. The reading time may be adjusted to 5, 10 or 60 minutes.

2. Preparing an operational record which consists of the delivery by the teletype of processed data from individual stations.

3. Preparing a disturbance record which is written by a separate teletype.

4. Checking the incoming measured values by comparison with preselected admissible limiting values.

5. Receiving via teletype the values of limiting intervals or their changes.

The digital form of measured quantity may be made available by wiring a digital to analogue converter. The central processing center serves presently for two purposes, one is to determine whether or not the concentration of any parameter exceeds the permissible level and the other is to gather summary characteristics concerning certain periods of time (e.g., one day) for long-range studies on the degree of water pollution in a given basin area.

The four basic units comprising the telemechanical equipment are a transmitter for measured values and messages, a receiver for measured values and messages, a transmitter of commands and a receiver of commands.

The first W-20 instruments were placed into operation during December of 1968. Table 2 demonstrates the results of the operating performance of the difference sensors. The average reliability of the measuring module was found to be in the order of 80 percent.

TABLE 2. Analysis of the Performance of Monitor W-20 Sensors from 1.12.68 to 15.08.70

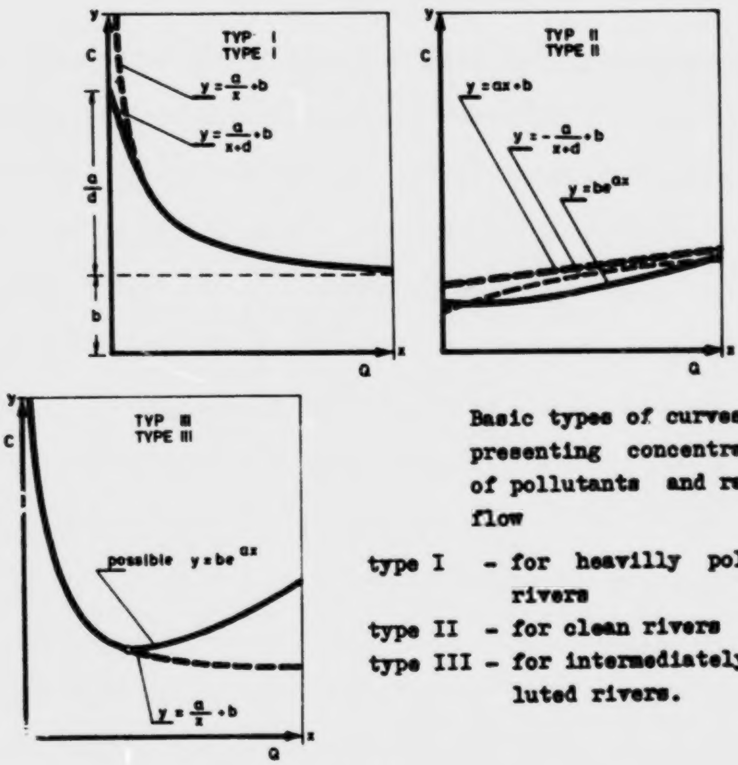
Sensors	Oxygen			Water Level			Conductivity			Turbidity			pH		
	68	69	70	68	69	70	68	69	70	68	69	70	68	69	70
1. Number of hours in the period	432	8760	5448	432	8760	5448	432	8760	5448	432	8760	5448	432	8760	5448
2. Operating hours	422	6916	4361	432	7934	4909	269	7311	4859	426	6358	4779	422	7306	4844
3. Operating hours %	97.6	78.9	80.0	100	90.5	90.1	62.2	83.4	89.1	98.6	72.5	87.7	97.6	83.4	88.9

	Redox potential			Temperature			Chlorides (from 1.07.69)			Solar radiation (from 18.04.70)					
	68	69	70	68	69	70	68	69	70	68	69	70	68	69	70
1. Number of hours in the period	434	8760	5448	434	8760	5448	-	4416	5448	-	-	2504			
2. Operating hours	404	7457	4859	327	7535	4899	-	3051	4716	-	-	2504			
3. Operating hours %	93.5	85.1	89.1	75.7	86.0	89.9	-	69.0	86.4	-	-	100			

The interpretation of data collected by the monitoring stations is subjected to somewhat different analyses than is usually performed elsewhere as described by Manczak (4). The Polish workers consider three types of flow-concentration curves to exist. These three curves, along with their equations, are presented on Figure 15. The Type 1 curve represents a heavily polluted river and the value of $\frac{a}{d}$ is considered to be the amount of wastes discharged and b represents the natural pollution of the river. The Type 2 curve represents a clean river and the intercept at $Q = 0$ is said to be natural pollution, increased flows representing pollution from sludge resuspension and runoff accumulation. Finally, the Type 3 curve is for pollution intermediate between the Type 1 and Type 2 curves. During low flows, dilution is said to be important while during high flows the important factor is sludge resuspension and runoff accumulation.

The magnitude of the number of observations made by the Polish workers allows the development of empirical equations on a statistical basis. For example, Figure 16 demonstrates a correlation between the initial five-day BOD and the value of the river deoxygenation coefficient. Figure 17 shows the flow concentration relationship developed, taking into account the temperature effects on BOD and Figure 18 illustrates the curves developed from previous considerations. Figure 19 through 22 demonstrate the types of flow-concentration curves utilized by the Polish workers in their water pollution control studies and regulation. Finally, Figure 23 demonstrates the results obtained using the W-20 monitoring station for a period of almost two years.

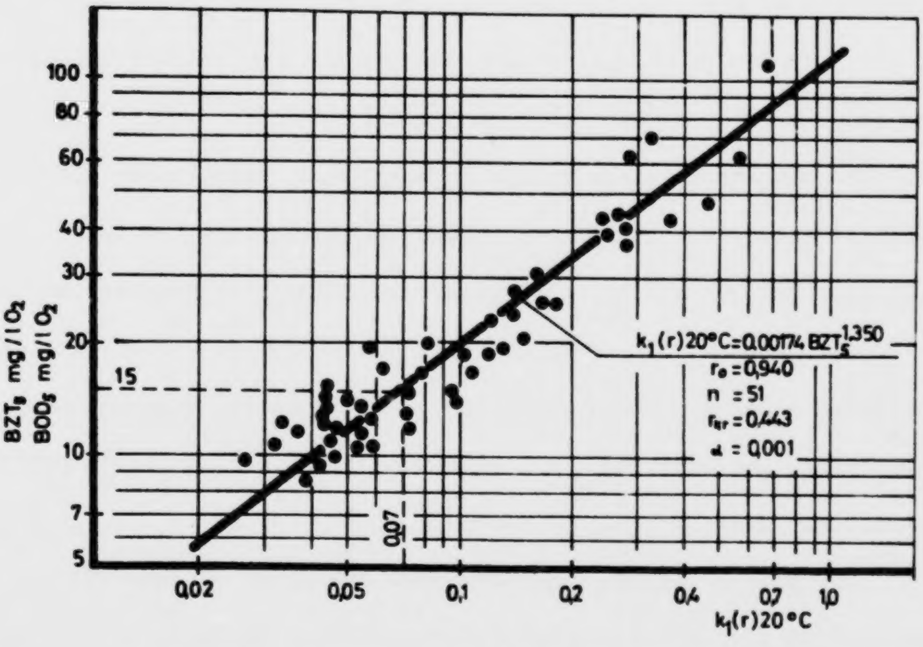
The Polish workers then take each parameter of interest and statistically analyze the data collected as shown in Figures 24 through 28. These analyses



Basic types of curves representing concentration of pollutants and rate of flow

type I - for heavilly polluted rivers
type II - for clean rivers
type III - for intermediately polluted rivers.

FIGURE 15



Correlation between initial BOD$_5$ and the value of k$_{1/r/}$ 20^{o}C coefficient

FIGURE 16

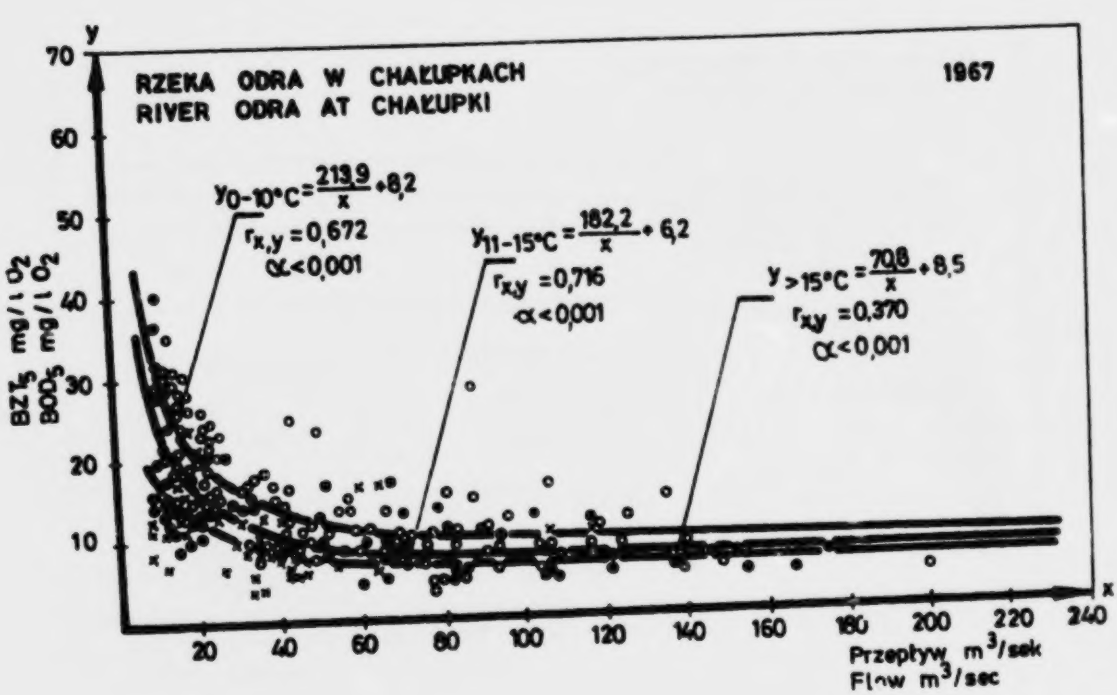
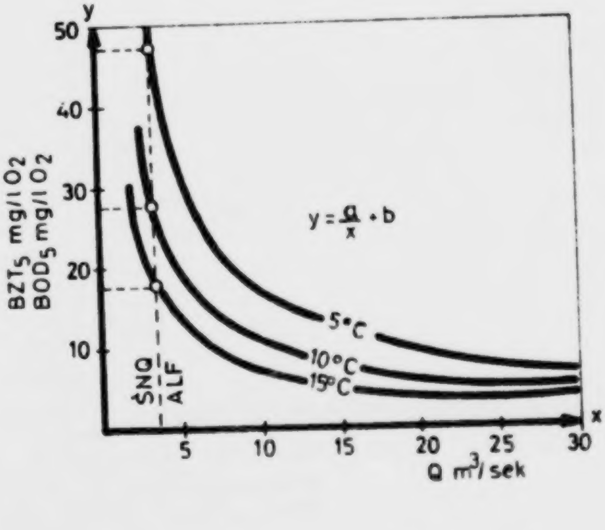


FIGURE 17



Relationship between BOD_5 and flow taking into consideration temperature effect

FIGURE 18

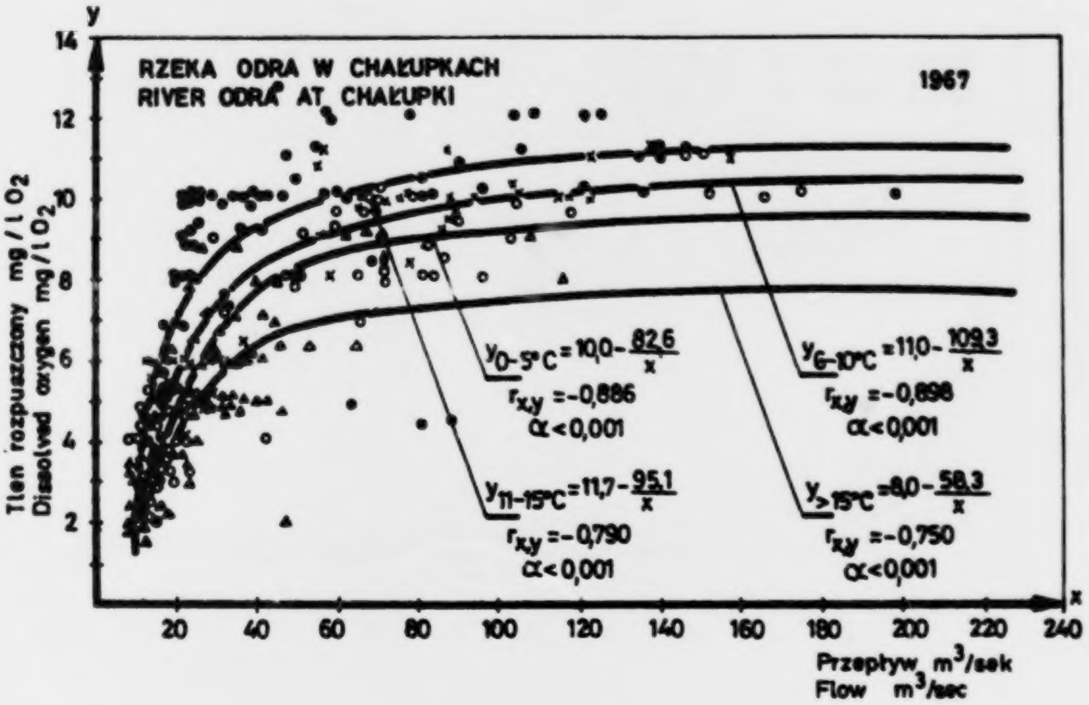


FIGURE 19

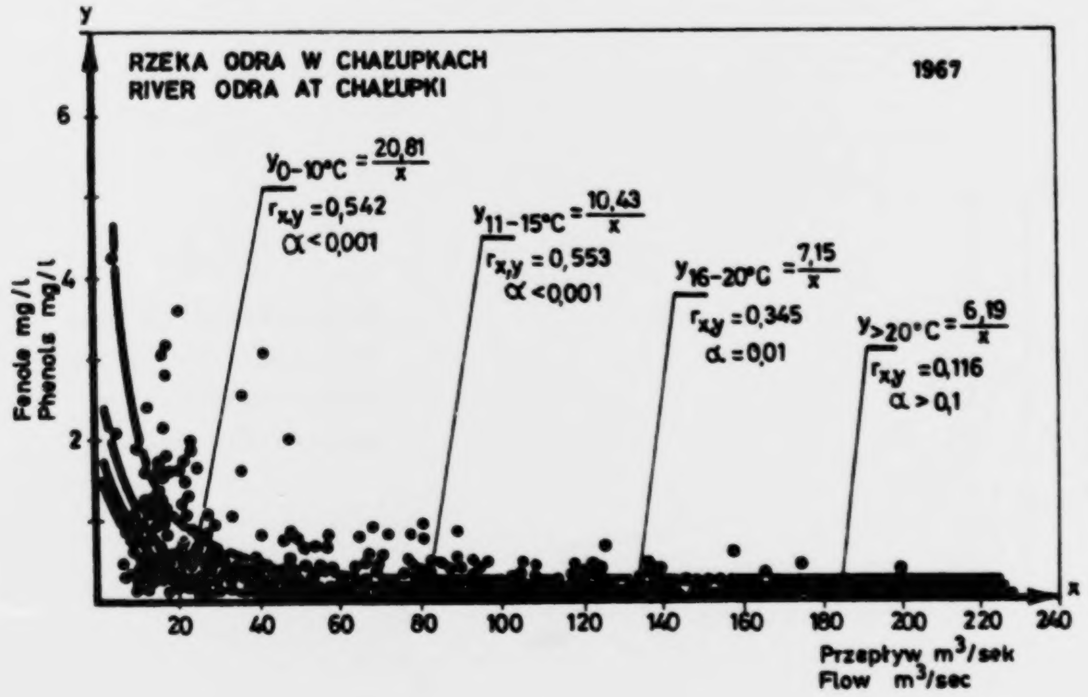


FIGURE 20

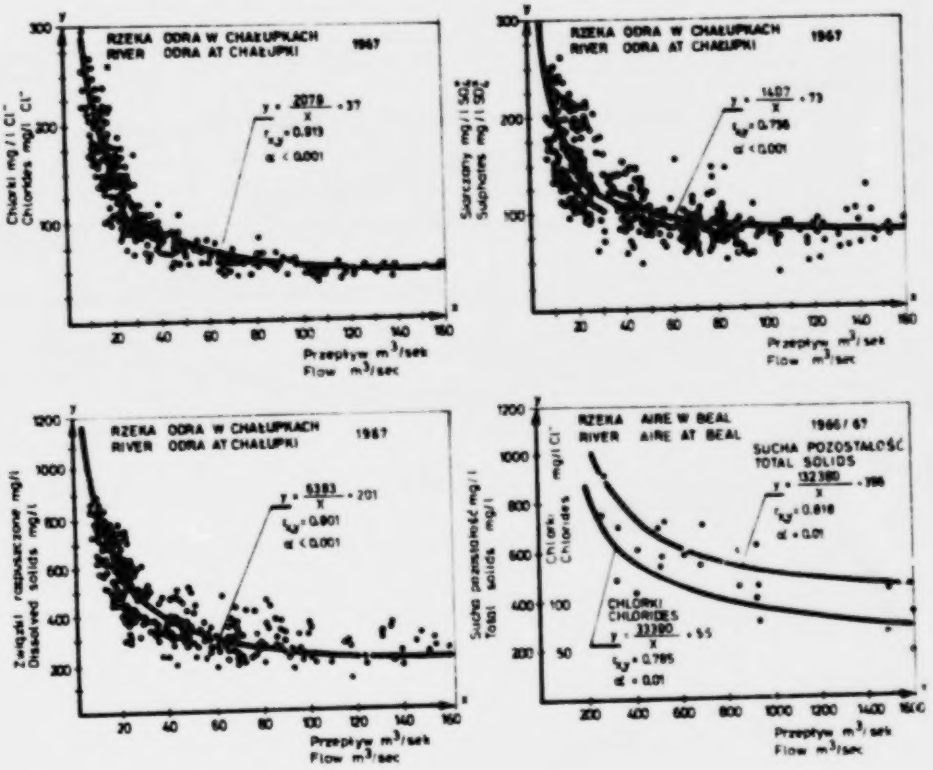


FIGURE 21

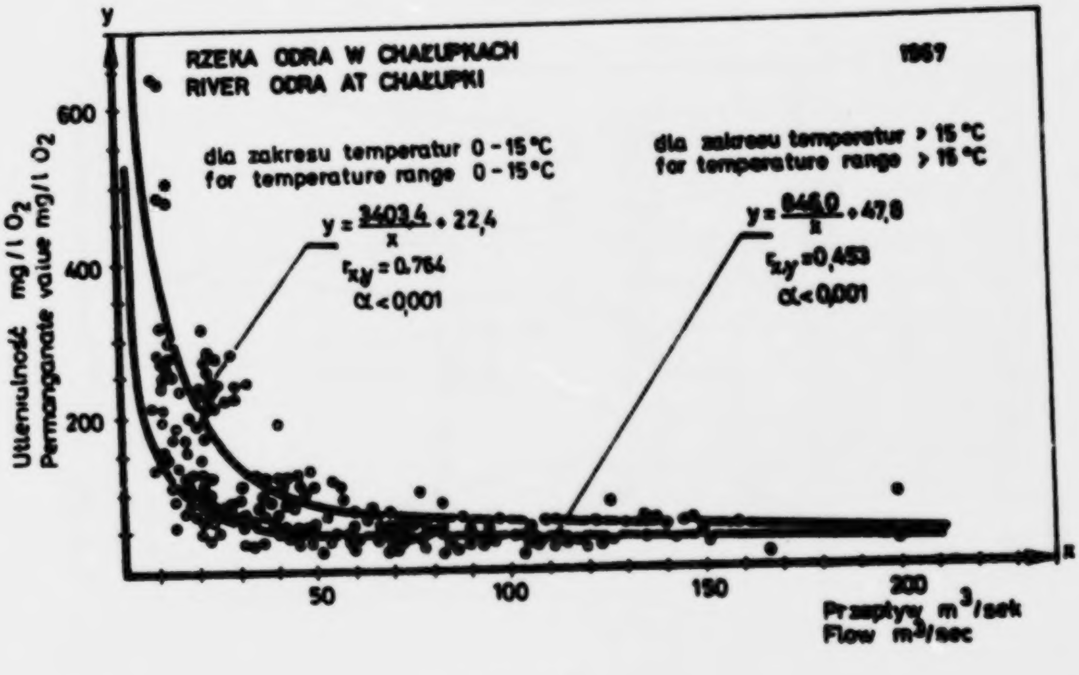
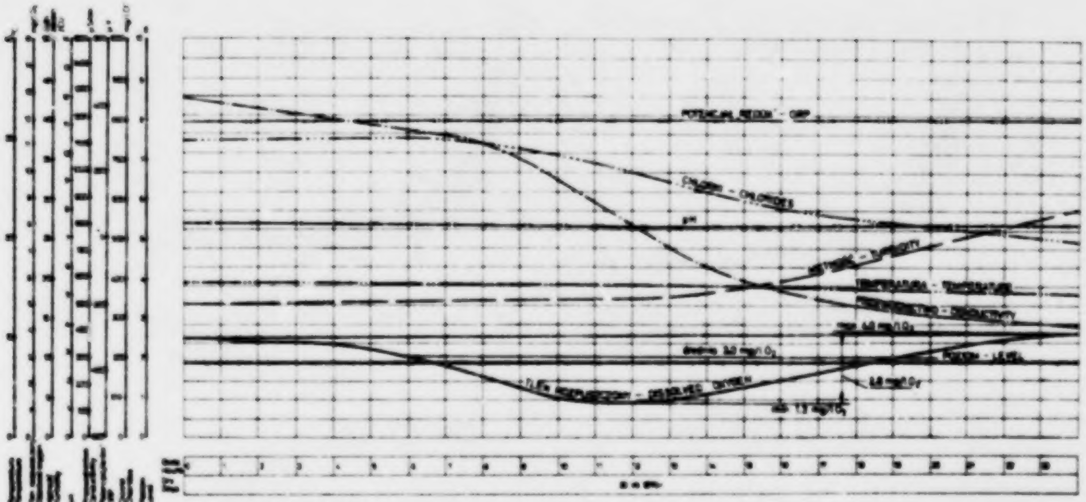
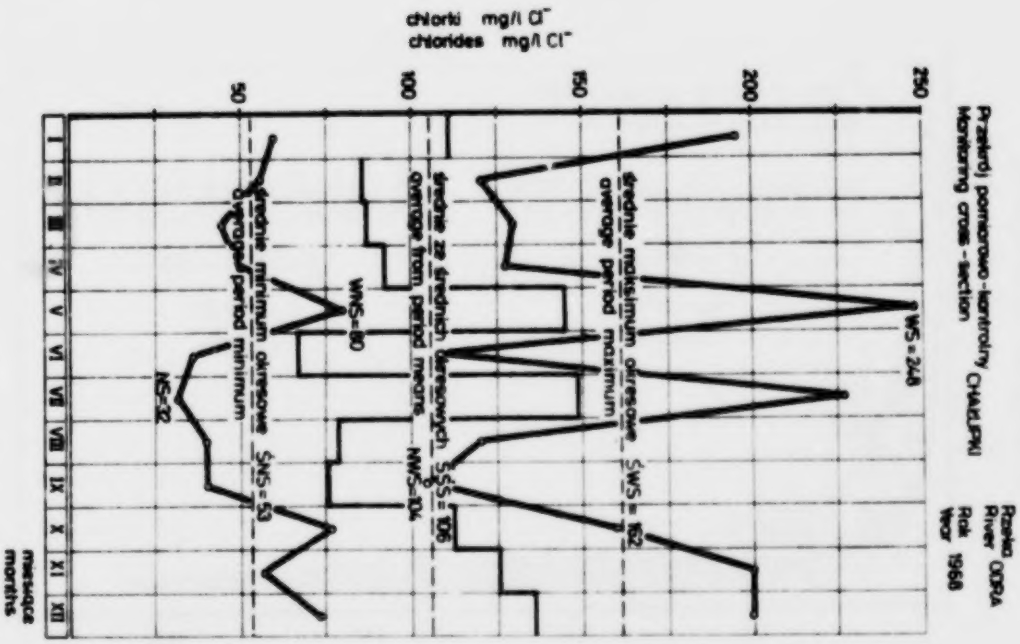


FIGURE 22



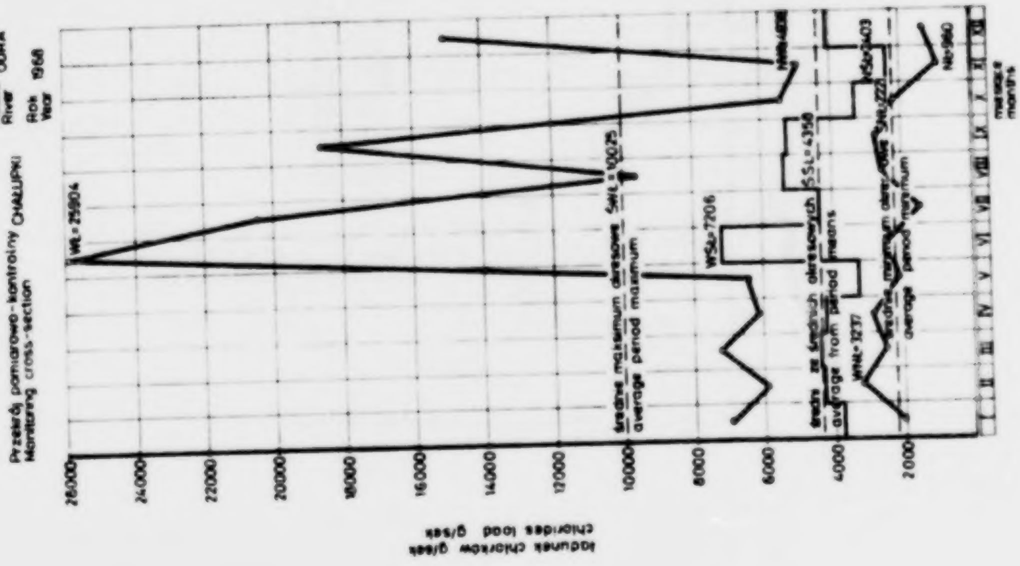
WYNIKI POMIARÓW W - 20
RESULTS OF W - 20 MEASUREMENTS

FIGURE 23



Time-duration curves of chlorides concentrations, loads and flow in Odra river at Chałupki, 1968

FIGURE 24



Plot of characteristic chlorides loads in Odra river at Chałupki, 1968

FIGURE 25

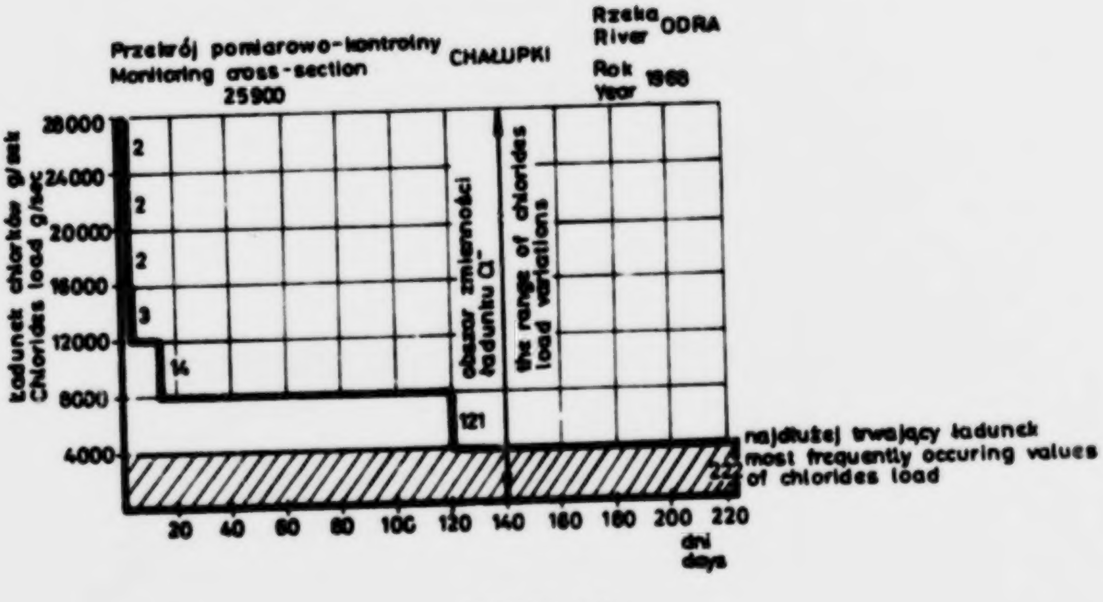
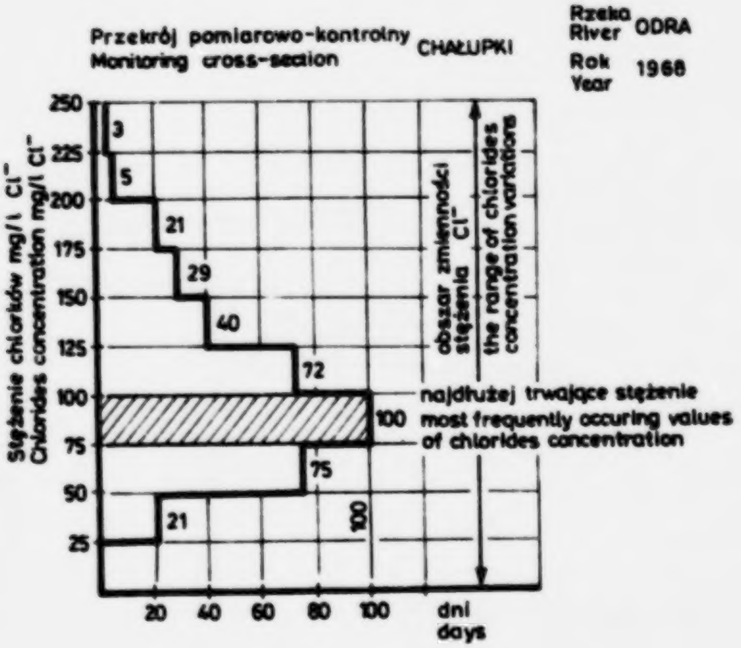


FIGURE 26



Frequency of occurrence curve of chlorides concentrations in Odra river at Chałupki, 1968.

FIGURE 27

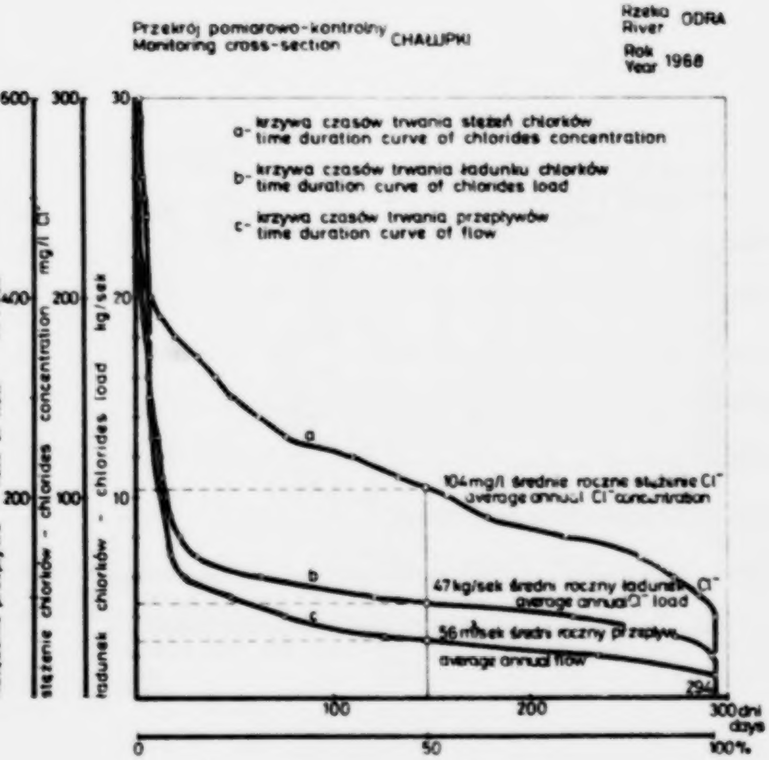


FIGURE 28

then form the bases for establishing standards and water quality goals in the river in question. While it may be observed that the Polish workers are able to collect much more data than is usually possible in the United States, their procedures appear to be quite rational and form a sound basis for the rational establishment of water quality goals.

Automatic Water Quality Monitoring in Czechoslovakia

In 1966, three experimental monitoring stations were installed on the Vltava River, downstream from Prague, on the Ohre River near Carlsbad and in Terezin. At these stations, Czechoslovakian made analyzers were tested for the monitoring of temperature, pH, DO, conductivity, chlorides, turbidity, color and different type pumps. New devices have been developed in Czechoslovakia for the automatic determination of pH, ORP, conductivity, DO and temperature. In addition, the central unit of the monitoring station has been developed so that it is able to transform signals coming from various analyzers into digital form for printing, magnetic tape or punched tape registration, in combination with telemetry, if needed. It is planned to place 50 automatic water quality monitoring stations throughout Czechoslovakia in the future.

Automatic Water Quality Monitoring in Hungary

A World Health Organization water quality management project has enabled the Hungarian workers to plan for five continuously operating automatic water quality monitoring stations in that country. The instruments installed are or will be Hungarian made and will measure temperature, DO, conductivity, pH, turbidity and solar radiation.

The data will be recorded graphically using a five point recorder and will also be connected to a telex system. This will allow interrogation of the station, resulting in printout of the water quality results on an hourly basis. Interrogation will be made from a center which will be located in the Hungarian Research Institute for Water Resources Development in Budapest where computer facilities are available. Statistical analysis of the data as well as data storage will be accomplished by the computer.

Three monitors are foreseen for the Sajo River, the first station, located at the Hungarian-Czechoslovakian border, was placed into operation in April of 1973. A second station on the Sajo will be placed into operation during December of 1973 and is approximately 69 kilometers from the first one. The third station will be a mobile one and will be mounted to a trailer. This will be used as water quality conditions require. The fourth station will be placed in the vicinity of the border between Hungary and Czechoslovakia and the location of the fifth station is not yet decided.

Summary and Conclusions

The status of water quality monitoring in Eastern Europe has been presented and the role of the World Health Organization delineated. It was shown that the most experience in the design and operation of these stations has been gained in Poland thus far, however, other countries are rapidly planning for comprehensive automatic water quality monitoring systems.

The procedures for the establishment of station locations in Poland were examined and it was seen that a considerable amount of care was exercised by the Polish workers. In addition, the vast array of data collected by the Polish authorities has resulted in some rather interesting relationships regarding river flow and concentration of certain pollutants.

It may be concluded that some substantial advances have been made in automatic water quality monitoring in Europe and that cooperation between European countries and the United States should be encouraged.

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AN AIRBORNE LASER FLUOROSENSOR
FOR THE
DETECTION OF OIL ON WATER

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An Airborne Laser Fluorosensor for the Detection of Oil on Water

A remote active sensor system designed to detect laser induced fluorescence from organic and biological materials in water has been suggested by a number of investigators. (1,2) Several different laser airborne systems are in the process of being developed in both the U.S. and Canada. (3,4)

In this presentation, we would like to report our successful operation of an airborne laser fluorosensor system which is designed to detect and map surface oil, either natural seepage or spills, in large bodies of water. The test flights were conducted in daylight preliminary results indicate that the sensitivity of the instrument exceeds that of conventional passive remote sensors which are available for the detection of an oil spill today.

The package was jointly developed by NASA Wallops Station and Sparcom Inc. of Alexandria, Va. The salient features of the system consist of a pulsed nitrogen laser, a f/1 28 cm diameter Cassegranian telescope and a high gain photomultiplier tube (RCA 8575) filtered by a U.V. blocking filter (0.01% and 0.3% transmission at 337 nm and 390 nm respectively). The laser produces a nominal 1 m joule pulse of 10 nsec duration at 337 nm contained in a retangular beam having a half angle divergence of approximately 30 by 2 mradians. The repetition rate 100 pulses per second affords one good spatial resolution when operated from an aircraft flying at 300 km/hr. Figure 1 is a photograph showing the laser equipment installed in NASA DC-4 aircraft.

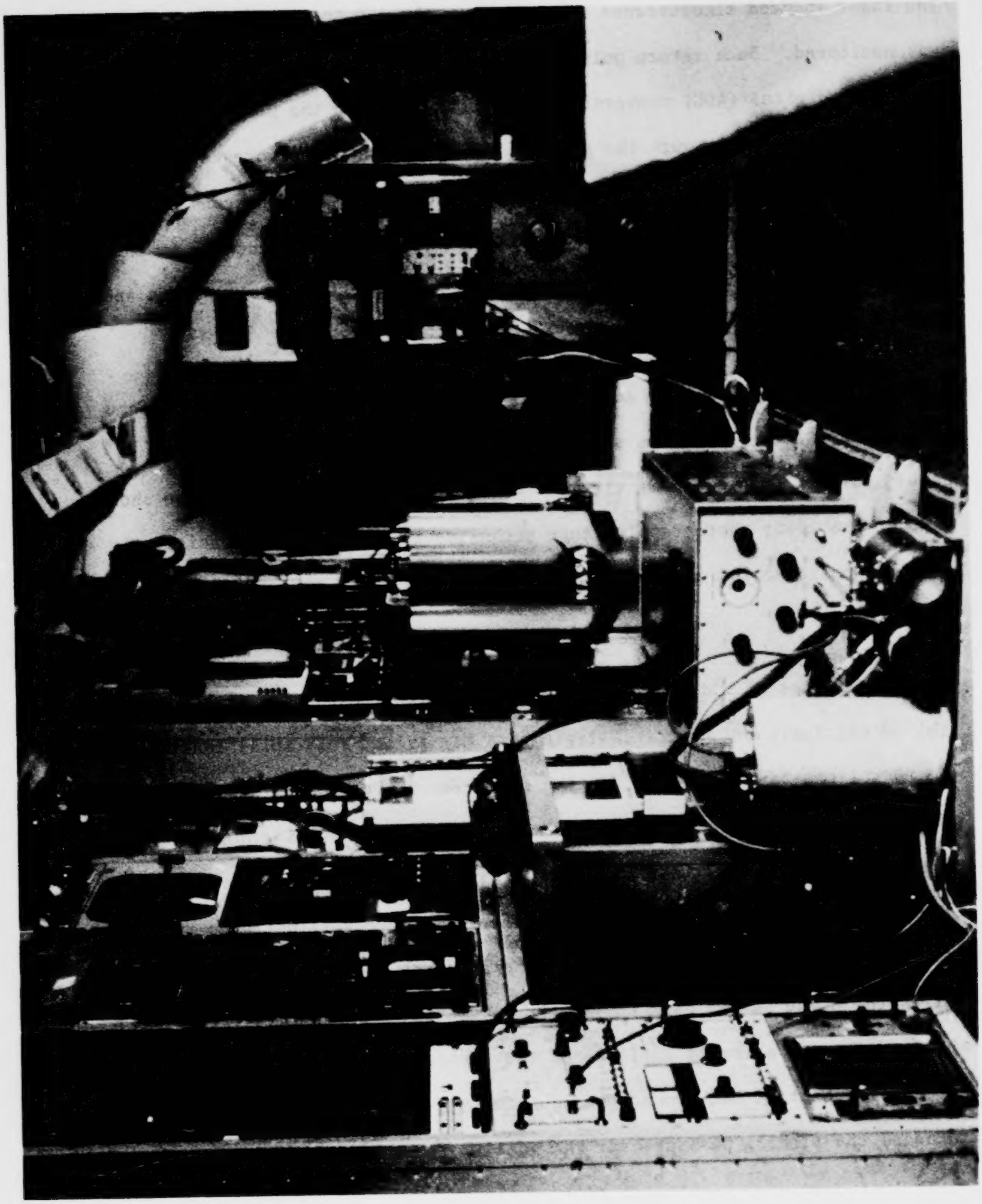

FIGURE 1 - Laser Fluorosensor Installed in NASA's DC-4 Aircraft

The laser induced fluorescence of the oil in the 450-500 nm spectral region was monitored. Each return pulse was fed into a range gated multi-mode analog to digital (ADC) conversion unit which recorded the peak amplitude of fluorescence. Even though the pulse width of the return fluorescence did not exceed 10 nsec, the width of the input gate to the ADC was considerably wider. This was to insure signal detection as fluctuations occured in the laser/oil distance which were produced by aircraft motion: roll, pitch and changes in altitude.

A 35 mm frame aerial camera equipped with a wide angle lens viewed the same area on the water surface as seen by the fluorosensor. Our experiences gained through previous NASA aircraft photo surveillance missions have shown us that the color photographic image technique is still one of consistently reliable positive indicators of the presence, position, and extent of the oil slicks.(5)

The first series of flight tests were conducted in conjunction with a controlled oil spill off Norfolk, Virginia in May 1973. This spill consisted of 400 gallons of No. 4 grade heating oil. The field experiments were managed by the U.S. Coast Guard. The NASA aircraft containing both the oil fluorosensor and a dual channel microwave radiometer,(6) flew over the spill site at altitudes ranging from 100-1000 feet. Figure 2 illustrates typical return signals which were obtained at the airborne receiver from the surface oil as the plane passed over the slick. The data shown in this figure was obtained from an aircraft altitude of 400 feet. This figure shows a large but fairly constant background previous to ($\leq$ 4 seconds) and after ($\geq$ 12 seconds) the plane's passage over the spill. There is a marked increase

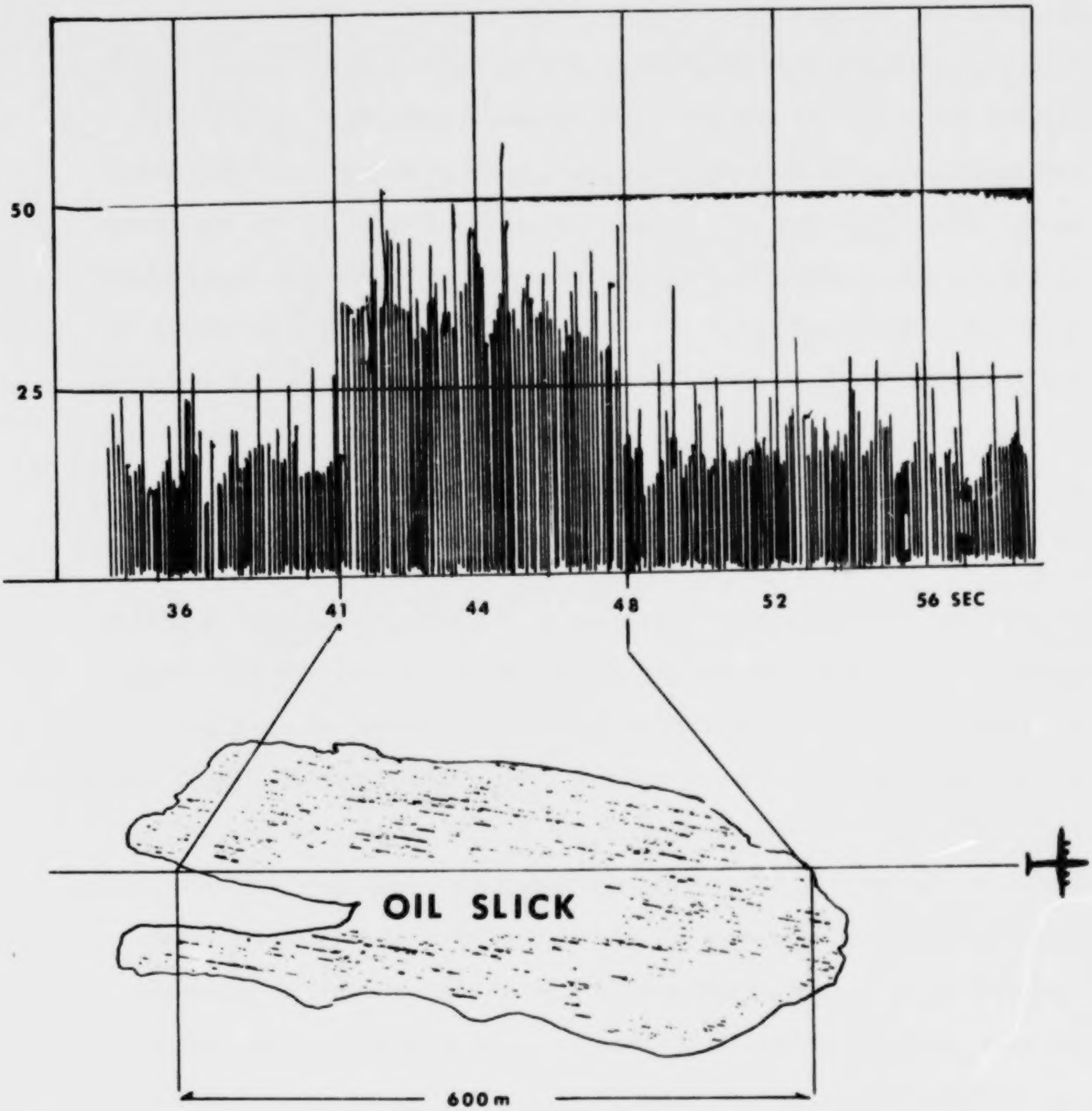

Figure 2: Typical Fluorescent Signals Observed with Laser Fluorosensor-Aircraft Altitude 400 Ft.

in the amplitude of the detected signal during the period of time that the aircraft was over the oil slick. Detection of the oil was recorded by the dual channel microwave radiometer during the time period of 6-8 seconds, which is close to the center of the spill. In all probability this represented the thickest layer of oil. This single qualitative experiment dramatically showed that while the microwave radiometer was able to detect the central portion of the spill, the increased sensitivity of the laser fluorosensor permitted detection of approximately the entire visual extent of the slick. Although the thickness of the oil changes as the oil spreads on the surface of the water, the amplitude of the fluorescent signal remained essentially constant (Figure 2). Since oil exhibits extreme absorption in the UV region of the spectrum one would expect the amplitude of the fluorescence to be relatively independent of thickness. This is in agreement with the flight test results. Confirmation of the dependence of oil thickness on fluorescence has been made in the laboratory.

A second set of flight tests consisting of six separate flights was made in August, 1973 to detect ambient oil on the Delaware River. Figure 3 shows the results of one of these flights from a 48 km section of the river between the Chesapeake and Delaware Bay Canal to the Delaware - Pennsylvania state line. The observed fluorescent intensity was approximately 5 times higher in the upper section of the Delaware River as in the lower section of the river. The background noise was substantially reduced over that recorded in the initial flight test. This was accomplished by narrowing the gate width of the digitizer input from 250 to 50 nsecs. The system was calibrated to register a value of 50 on the ADC unit against a thin oil film target in full view of the receiver at an altitude of 500 feet

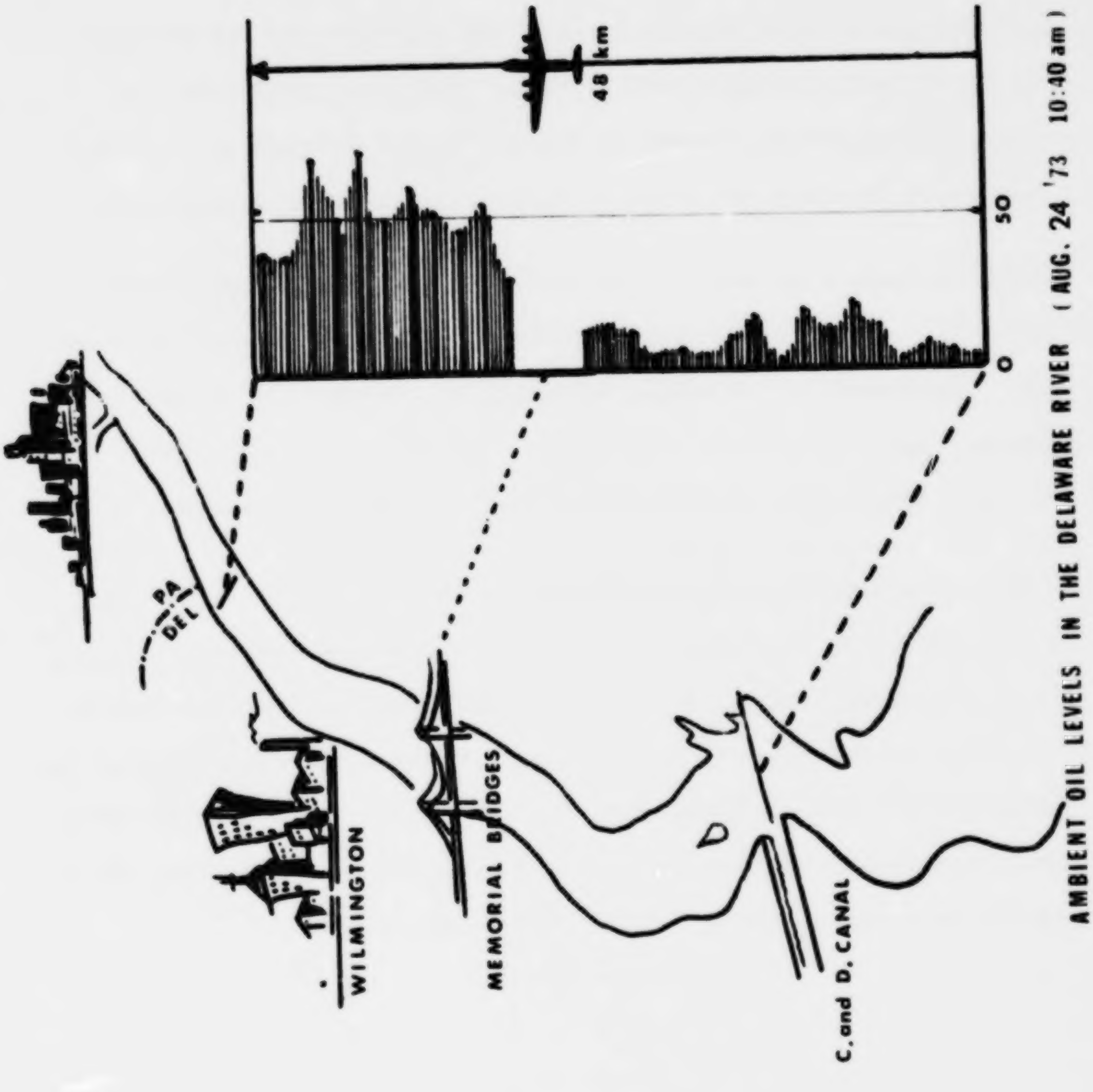

Figure 3 - Ambient Oil Levels in the Delaware River Measured with the Airborne Laser Fluorosensor. (Aug. 24, 1973 10:40 a.m.)

and a value of zero against ambient noise in the open sea. This was accomplished by adjusting the gains of the phototube and the threshold levels of the input discriminator to the digitizer. Therefore, our calibration procedure assured us that the signal observed in the lower section of the river was a real fluorescence and not background noise.

Figure 4 shows a bar chart of the morning flight results, previously shown in Figure 3, along with the return afternoon flight made the same day. Each block in the figure represents an average value of 3000 return pulses. This figure shows dramatically the change in the intensity of the oil in the lower section of the river in a fairly short time.

Images from the aerial photography showed the presence of oil when a scale reading of 50 or greater was reached on the ADC output. Therefore, photography did not show the presence of oil in the lower section of the river during the morning flight, although detection of the oil was made with the laser fluorosensor. This is significant, in that it shows the tremendous sensitivity of the laser fluorosensor in detecting traces of oil that can not be detected by other remote sensors.

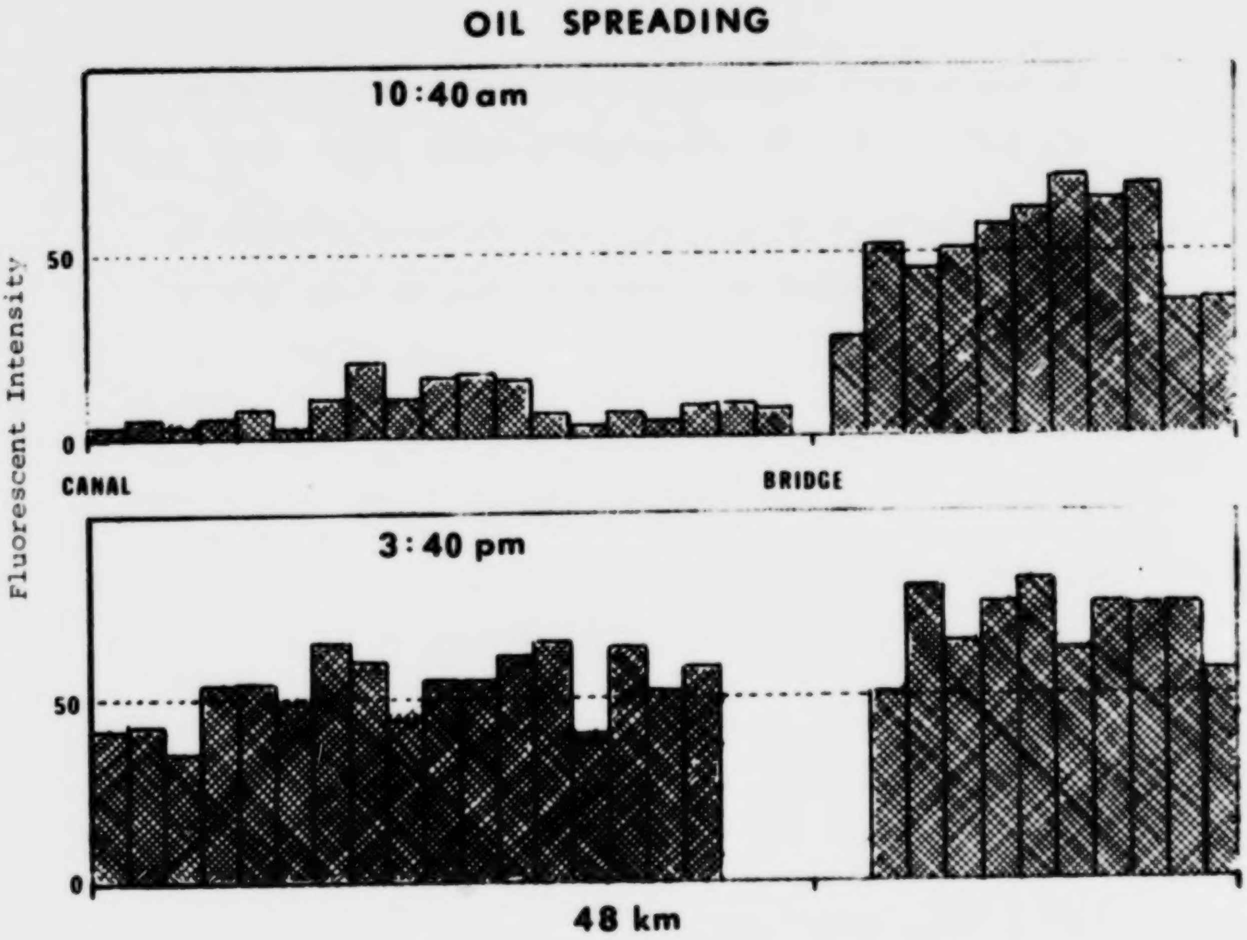

Figure 4 Oil Spreading in Delaware River Observed with an Airborne Laser Fluorosensor

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SESSION V.

ENVIRONMENTAL THEMATIC MAPPING

CHAIRMAN

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OFFICE OF MONITORING SYSTEMS, OR&D

THE U.S. GEOLOGICAL SURVEY AND LAND USE MAPPING *

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BACKGROUND

A modern nation, as a modern business, must have adequate information of many complex, interrelated aspects of its activities in order to make decisions. Land use is only one such aspect, but it is one that has become increasingly important as the Nation seeks to grapple with the problems of suburban expansion, demand for outdoor recreation, highway and transportation planning, environmental quality, and use of energy resources. The land area of the United States is a finite quantity that has not changed very much for more than a century and is not likely to change in the future. However, the uses made of the Nation's land and water resources have changed greatly.

Urbanization has been absorbing land at the rate of about 730,000 acres per year during the 1960's and another 130,000 acres per year were being transferred to transportation uses from other uses. About 1 million acres per year have in part been going into some kind of recreational use during the past decade. In the future, the possible use of strip mining to increase the exploitation of coal resources could bring significant land use changes to those areas of the Nation where strippable coal deposits exist. To date about 1.5 million acres of land have been disturbed by strip mining of coal but as much as 45 million acres with strippable coal deposits exist in the United States.(1)

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* For oral presentation and possible publication in the Proceedings of the U.S. Environmental Protection Agency's Second Environmental Quality Sensors Conference, Las Vegas, October 11, 1973.

Therefore, the growing population of this country coupled with a widening horizon of demands being made on land resources has brought an expanding array of pressures on the available resource base. These pressures have brought conflicts in many parts of the Nation that urgently need attention. Some examples include agricultural production in conflict with real estate development and resulting urbanization; environmental protection versus production of energy to meet increasing demands for power; recreational development versus the use of land for forestry, grazing, and extractive uses; conservation of coastal areas for recreational uses in the face of needs for more port facilities and shoreline industrial sites; preservation of wetlands for natural wildlife and fisheries habitat in the face of new demands for development of such wetlands for urban uses, agricultural production, and other uses.

In recent years Americans in general have become more and more concerned about resources and their use, about the quality of the environment, about urbanization of productive agricultural land, need for recreational development closer to where they live, and many other local, state, and national resource issues. However, there is a widespread lack of understanding of resource use and environmentally related problems. For example, the current furor over the high cost of food, particularly meat, might be more rational if more Americans realized that an average acre of land is hard pressed to produce 500,000 calories of food per year if used for beef production. When used to produce wheat or rice that average acre can produce about 2 million calories of food annually. Each American consumes about a million calories a year. The Chinese are not vegetarians by choice but by necessity. Peanut butter has as much protein per pound as beefsteak but obviously most Americans are still insisting on eating beef. I well remember when I was a boy in the 1930's how disgraceful my mother always considered it was to serve oleomargarine. Today many of us use it as an acceptable substitute for butter - that is until the recent rise in the price of soybeans caused a significant narrowing of the price spread between oleomargarine and butter.

Another example of American's general lack of understanding of resources and their use relates to the present scarcity of energy. When I was growing up on a farm in the White River Valley of Indiana, we used only 30 kwh of electricity per month. Recently when I paid my last electric bill in moving from Florida to Reston, Virginia, our family had used 1,543 kwh in the month of December, a good month for Florida. This great expansion in the consumption of energy by Americans has brought us rather abruptly to an agonizing reappraisal of priorities and options necessary to bring about a solution to the current energy shortages compatible with the need to maintain and improve the quality of the environment.

NEED FOR LAND USE DATA

The increasing number and complexity of land use conflicts indicate a need for positive private and public planning efforts to resolve these acute problems and to prevent or reduce future conflicts. The severe strains being placed upon the natural environment in many parts of the country must be reduced and the stresses on social, political, and economic institutions must be relieved. Improvement in the land use decision making processes at local, state, and Federal levels is one way of reducing these strains and solving these problems.

Many responsible public officials and prominant authorities on land resource planning, decision making, and management have stressed the need for more information about existing land use. For example, Marion Clawson, former Director of the Bureau of Land Management, author of numerous books dealing with land resources, and for several years with Resources for the Future, makes the following statement in the Foreword to a report published in 1965 on Land Use Information: A Critical Survey of U.S. Statistics Including Possibilities for Greater Uniformity:

> "In this dynamic situation, accurate, meaningful, current data on land use are essential. If public agencies and private organizations are to know what is happening, and are to make sound plans for their own future action, then reliable information is critical."(2)

Pending legislation in the 93rd Congress recognizes the need for Federal participation in the collection of land use data. In Senate Bill 268, Title II, Section 202, the Secretary of the Interior, "Acting through the Office (of Land Use Policy Administration), shall:

A) Maintain a continuing study of the land resources of the United States and their use:

B) Cooperate with the States in the development of standard methods and classifications for the collection of land use data and in the establishment of effective procedures for the exchange and dissemination of land use data: ..."(3)

H.R. 4862 is also quite specific on the need for adequate information on land use. In Section 101 of Title I, the following statements are made:

> "The Congress finds that adequate data and information

> on land use and systematic methods of collection, classification, and utilization thereof are either lacking or not readily available to public and private land use decision makers; and that a national land use policy must place a high priority on the procurement and dissemination of useful land use data."(4)

One of the prime requisites for better use of land is information on existing land use and changes in land use over time. The present distribution of agricultural, recreational and urban land; knowledge of how and where urbanization and other development has been occurring; and data on the proportions of a given area recently devoted to different uses are used by the legislators and state officials to determine land use policy, and by planners to project transportation demand, identify areas where future development pressure will be greatest, estimate future infrastructure requirements, and develop more effective plans for regional development.

Another possible use of current land use data is in equalization of tax assessment procedures among counties. A representative of a State revenue office indicated that current statistical data on different land uses in each county would be invaluable to the State in reviewing assessment reports submitted by county assessors.

Information on existing land use and changes in land use is also of significance for water resource planning. As land is changed from agricultural or forestry uses to urban uses surface water runoff increases in magnitude, flood peaks become sharper, surface and ground water quality deteriorates, and water use increases thereby reducing water availability. By monitoring and projecting land use trends it will be possible to develop more effective plans for flood control, water supply, and waste water treatment.

Federal users also need current land use information. The assessment of recreational needs and opportunities requires knowledge of the location and extent of urban areas and potential recreational lands. This information is used to forecast demand, identify potential solutions, and develop recreation plans. Comprehensive inventories of existing uses of public lands plus the existing and changing uses of adjacent private lands can improve the management of public lands. Other Federal uses of land use data include assessing the impact of energy resource development, water resource and river basin planning, managing wildlife resources and studying changes in the use of lands in the migratory bird flyways, and preparing national overviews of changes in the use of land for national policy formulation.

Another application of land use data is in assessing the impact of natural disasters such as floods. Statistics on the acres of agricultural, urban and other types of land inundated by flood waters would be invaluable in estimating damages, future crop losses, and consequent econimic impacts.

Presently, there is no systematic compilation of information on existing land use and its changes on a national basis. For detailed planning at the local level, ground surveys, occasionally supplemented by aerial photographs, are used. In some cases, land use information is hypothesized on the basis of data on utility hookups, school population, building permits, and similar information. Transportation planners collect the necessary information using similar techniques.

Some States such as Connecticut,(5) New York,(6) and Minnesota,(7) have land use information available on maps at scales ranging from 1:24,000 to 1:500,000, but in most cases these States have not been able to update the land use maps, therefore, they have decreasing utility. Some Federal agencies, such as the Forest Service, Soil Conservation Service, and Bureau of Land Management, collect some land use information, but it is for a specific need and is difficult to adapt to other uses. In 1958, and again in 1967, a National Inventory of Soil and Water Conservation Needs was carried out by the U.S. Soil Conservation Service.(8) The inventories have provided much useful general information about land uses by counties, but since the inventory was based on a two percent sampling of the total area of the United States it is deficient with respect to specific geographic distributions of various land uses.

Some of the major problems with these existing data sources are the lack of consistency, the age of the data, spotty coverage, and the use of incompatible classification systems. The data have been collected to meet specific limited needs using definitions of use classes which are appropriate for only that need. They have often been collected on a one-time basis so the data are of marginal utility for other applications. Furthermore, it is nearly impossible to aggregate the available data because of the differing classification system used.

DEVELOPMENT OF A LAND USE DATA PROGRAM

A step to develop a framework for the meaningful classification of land use on a nationwide basis has been taken by the U.S. Geological Survey. In Geological Survey Circular 671 entitled "A Land Use

Classification System for Use with Remote Sensor Data," published in October 1972, a land use classification system is proposed for testing and review. This classification system has been developed to meet the needs of Federal and State agencies for an up-to-date overview of land use throughout the country on a basis that is uniform in date, scale, and categorization at the more generalized first and second levels. Remote sensor data will definitely be the most cost-effective method of acquiring such land use information. Data from ERTS-1, from high altitude aircraft platforms, and from the Special Mapping Center of USGS at Reston, Virginia are available for obtaining land use information. The classification system utilizes the best features of existing widely used classification systems to the extent that they are amenable to use with remote sensing, and it is open-ended so that regional, state, and local agencies may develop more detailed land use classification systems, at third and fourth levels, to meet their particular needs and at the same time remain compatible with the national system.

There has been longstanding use of remote sensing technology in land resource inventory and mapping. In the 1930's the Tennessee Valley Authority made extensive use of air photographs in land and water resource surveys. The U.S. Soil Conservation Service has found aerial photography invaluable for soil surveying and the U.S. Geological Survey has for many years also made extensive use of air photographs in its Topographic Mapping Program.

However, only in the mid-1960's was there a growing recognition of the utility of the technology of remote sensing for extensive resource-oriented land use inventory and mapping. We now have the remote sensor capability to map effectively the land uses of the entire

United States within a reasonable time frame of approximately three years. We also have been working to provide an effective and efficient approach to the periodic updating of land use data. While it is not possible to collect all of the information about land use from remote sensor sources that is needed for planning, management, regulatory, and other purposes, experiments presently being carried out in the Geological Survey and elsewhere indicate the desirability of using remote sensing technology as much as possible if cost effective inventory and mapping of land use is to be achieved.

Because land use data are highly perishable and need to be updated frequently it is very necessary that the compilation and dissemination of such data be in accord with a schedule compatible with the need for updating at regular and frequent intervals. Some areas have a much more dynamic land use situation than do others, therefore the need for updating land use data is not uniform throughout the country. For example, rangeland and tundra areas of the Western States and Alaska respectively do not generally need surveying nearly as frequently on the whole as do areas around major cities, many coastal areas, areas of critical environmental concern, and areas of recreational impact.

In order to accommodate the need for promptness and regularity in land use inventory and mapping, it will be necessary to revise traditional approaches to the compilation and dissemination of land use data. Traditionally land use data have been compiled on attractive multi-colored lithographed maps that were generally out-of-date before publication. The United Kingdom has had two land use surveys - one in the 1930's and the other in the 1960's that utilized this approach.

More recently Japan is publishing a series of land use maps that show great detail about the uses being made of land in that country.

Land use data has been presented at a great variety of scales ranging from detailed scales of 1:10,000 or even larger scale for metropolitan planning to very gross scales such as 1:2,500,000 and 1:5,000,000 used for the very attractive land use maps of the World Atlas of Agriculture presently being published in Italy. In the United States it seems appropriate for nationwide coverage in land use mapping and inventory to use a scale of 1:250,000 for which an existing base map is available for presentation, with scales of 1:24,000 or 1:50,000 utilized for selected areas where greater detail in land use data is needed.

In the future, careful considerable will need to be given to the use of computer-generated graphic and tabular displays of land use data in order to achieve the timeliness and regularity of presentation needed by many of the users of land use information. Use of computer technology is also very important from the standpoint of developing the capability of making rapid and varied comparisons of land use data with other data sets pertaining to land resources such as slope, soil type, access to various kinds of transportation, population density, etc.

The approach to land use classification being proposed by the U.S. Geological Survey is resource-oriented. In contrast to the people-oriented system developed inthe mid-1960's by the Urban Renewal Administration and the Bureau of Public Roads and published as the Standard Land Use Coding Manual.(5) The people-oriented system assigns 7 of the 9 more generalized first level categories to urban uses of land which account for less than 5 percent of the total area of the United States. This 5 percent of the area has, however, about 95 percent of the total population of the United States - thus a real need exists for an urban-oriented land use classification system.

However, it has become increasingly apparent that a resource-oriented land use classification system is also needed. The USGS classification system has been developed to meet that need. Eight of the proposed nine Level I categories are associated with the 95 percent of the total area of the United States not in urban and built-up uses. A considerable degree of compatiblity between these two systems of classification can be achieved at the more generalized levels. However, complete compatiblity can probably not be achieved between land use data collected from ground observation and enumeration and that compiled from remote sensor sources, particularly at the more detailed levels of categorization.

In developing a land use data program with a resource orientation several basic general assumptions, needs, and requirements have been recognized.

In the first place, there is much evidence that there is a need for an effective national and interstate regional perspective of the major uses of land in the United States. Federal and State agencies engaged in land management and planning activities need to have a comparable set of land use data in order to carry out various Federal and State interagency activities effectively.

In the second place, it has been assumed that no one ideal land use classification will ever be developed. Therefore provision has been made to provide for flexibility but at the same time make it possible to summarize and generalize on a reasonably uniform basis

Thus each Federal agency and each State will be able to develop an extension of the USGS classification system appropriate for their specific needs. In other words, no attempt will be made to develop or seek adoption of a common approach to the categorization of land use at the more detailed Levels III and IV.

Thirdly, it has been clearly demonstrated that remote sensor data offer the most efficient and least costly means of compiling land use data over extensive areas at the more generalized Levels I and II in the USGS land use classification system. In using remote sensor data at the main data base, it is necessary to use a "cover" approach to land use classification rather than an "activity" approach. Farming, grazing, and forestry are activities: cropland, rangeland, and forestland are cover-oriented categories.

In the development of the USGS land use data program provision is being made to accommodate the need for additional items of land use data that cannot be provided directly from remote sensor sources. For example, the outdoor recreational uses of land are often very difficult to determine from remote sensor data. Hunting may be associated with several different uses of land. Data on hunting activity gathered by enumeration and ground observation can be included as an overlay or additional data set in the Geographic Information System being developed for the handling and dissemination of land use data in the U.S. Geological Survey.

Demonstration of a reasonable level of accuracy in compiling land use data from remote sensor data sources must be made if there is to be widespread acceptance of the land use data compiled from such sources. At the more generalized levels of categorization correct interpretation of land use 85 to 90 percent of the time is considered to be an adequate level of accuracy. Often overlooked is the fact that data collected by enumeration and ground observation techniques is generally not infallible. For example, in the Census of Agriculture taken every five years by the U.S. Bureau of the Census, there is generally an under-enumeration of about 7 to 8 percent with incorrect enumeration of land use items on an additional 5 to 10 percent of the farmland being enumerated.

In the Land Use Data Program of the U.S. Geological Survey, attention is being given only to the compilation of present or current land use data. No attempt is being made in this program to rate or evaluate the capability or suitability of land for residential, agricultural, recreational, or other uses.

EXPERIMENTAL PROGRAM PRODUCTS

Specific products being provided experimentally and operationally by the USGS Land Use Data Program are:

- Transparent overlays depicting current land use classified by the 34 categories in Level II of the USGS land use classification system formatted to the standard 1:250,000 scale topographic maps and showing the political units, major classes of public land ownership, river basins and sub-basins, and statistical recording areas such as census tracts.
- Transparent overlays formatted to a photo-image base at 1:50,000 scale showing existing Level II land use for selected Standard Metropolitan Statistical Areas (SMSA), and other areas where a larger scale is needed.

- Computer-generated graphic displays (maps) at 1:250,000 scale.
- Computer tapes of current land use data (for those users who desire the data in this form and who have appropriate computer capability).
- Computer-generated overlays showing the changes in land use for intervals of from three to ten years, depending on the area.
- Statistical data on land use patterns and changes for various political, statistical, and administrative units.

SUMMARY

Clearly stressed in the 1972 Report of the Citizen's Committee on Environmental Quality is the fact that "Of all the factors that determine the quality of our environment, the most fundamental is the use we make of our land." This is true not only in the big urban centers of our country where such problems as air and noise pollution plague us and often go unresolved, but land use is also a key factor in determining environmental quality in the most remote rural and relatively untouched parts of the Nation. Each situation bears careful study and evaluation as a basis for action before steps are taken to resolve conflicts and relieve pressures relating to conservation and development of resources. Such evaluations should be based on the best available facts about current, past, and possible future land use patterns and the many varied conditions that determine those patterns. To date many of the basic facts have been lacking over extensive parts of the Nation.

In summary, land inventory and resource analysis should always include and recognize the need for:

1. Timely and cost-effective inventory procedures including current land use with geographic location capability;

2. Regular monitoring of change in quality and use of land and water resources;
3. Standardization of classification systems;
4. Capability for effective integration and synthesis of information;
5. Systematic and regular analysis of changing patterns of resource use.

* * *

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REMOTE SENSING DATA, A BASIS FOR MONITORING SYSTEMS DESIGN

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A paper for the U.S. Environmental Protection Agency's Second Conference on Environmental Quality Sensors. EPA National Environmental Research Center, Las Vegas, Nevada, October 10-11, 1973.

1 October 1973

REMOTE SENSING DATA, A BASIS FOR MONITORING SYSTEMS DESIGN

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ABSTRACT

Recent remote sensing investigations of large river systems bordering Iowa have demonstrated that rapidly acquired remotely sensed data can effectively provide information for monitoring systems design. A thermal remote sensing survey of 180 miles of the Mississippi River was conducted by the Iowa Geological Survey, Remote Sensing Laboratory prior to the operation of a nuclear power plant in the Davenport-Moline area of Iowa-Illinois. Thermal mapper data provided information on locations of sources of thermal effluent, surface current distribution patterns in the river, and relationships between thermal regimen of slough areas and river channel. Interpretation of this data can provide infomation for the placement of monitoring sensors and their synoptic nature can provide the insight into regional environmental patterns. An aerial photographic flood mapping mission was flown over 70 miles of the Nishnabotna River in western Iowa. The purpose of this mission was to accurately map distribution of flood high water several days after waters recede. This remote sensing investigation provided data on the extent of floodplain inundation following a 100-year recurrence interval flood. Interpretation of this data can provide information on the nature and areal extent of the floodplain. Delineation of the floodplain can provide information for solid and liquid waste management, and for development of environmental disaster plans.

THERMAL MAPPING OF THE MISSISSIPPI RIVER IN IOWA

Along the Missouri and Mississippi rivers bordering Iowa power companies, industries and municipalities contribute thermal effluent to the thermal regimen of these river systems. The Atomic Energy Commission and power companies are pressing for the development of Atomic Power plants which would use river water for cooling purposes and return the heated water to the main channel. Warm effluents, nutrients from runoff over agricultural land, and effluent from waste treatment plants provide the ingredients for a major pollution problem along these river systems. Alternative solutions to the cooling problem (use of groundwater, cooling towers, and cooling ponds) are expensive solutions, and in some cases unsatisfactory solutions for the cooling requirements.

Development of an environmental water quality surveillance system requires knowledge of the natural and manmade characteristics of the hydrologic environment. For a large hydrologic system, like the Mississippi River, gathering data by conventional ground techniques can be an expensive task, both in terms of time and money. Granting permits to operate requires analysis of environmental impact and usually little time or money is available for extensive data collection. Use of the remote sensing approach can provide a synoptic overview of entire systems, and can provide data for the location of ground instrumentation.

In the spring of 1971 Commonwealth Edison Company sought to establish a diffuser pipe in the Mississippi River near Cordova, Illinois. At that time little was known of the thermal regimen of the river surrounding Cordova, and pressure from environmentally oriented groups in Iowa demanded that thermal data be gathered on a regional basis. In cooperation with the Iowa Conservation Commission, Commonwealth Edison, and several other Iowa state agencies, Iowa Geological Survey decided to acquire remotely sensed thermal mapper data over a large portion of the Mississippi River as it borders Iowa. The decision to acquire remotely sensed thermal data was based upon:

1. The limited amount of time available to determine the thermal characteristics of the river around the proposed diffuser pipe at Cordova;

2. The considerable expense of extensive point data collection studies over several hundred miles of river;

3. The uncertainty of point data acquired by probe and thermometer instrumentation. Generally point data acquired by these instruments do not measure the thermal flux out of the skin of the river and thus the heat budget of the system is difficult to assess. Also, large variations in temperature can occur within a few inches of the river surface, and unless considerable care is taken with conventional measurements, large uncertainties can be introduced by inadvertantly measuring temperature at varying depths.

4. The uncertainty introduced by interpreting point data and contouring these data.

5. The contemporaneous nature of thermal mapper data. Contemporaneous point data requires extensive ground instrumentation.

In the spring of 1971 Commonweulth Edison Company agreed to fund a data acquisition remote sensing mission over the Mississippi River from Clinton to Keokuk, and to supply Iowa Geological Survey with one copy of all imagery for unrestricted public use. Pre-flight planning and the mission were coordinated by Dr. Samuel J. Tuthill, State Geologist of Iowa, Donald B. McDonald, Civil Engineering Department, University of Iowa, and by Victor I. Myers, director of the Remote Sensing Institute at Brookings, South Dakota. The Remote Sensing Institute at Brookings acted as technical consultants for mission design and data analysis. In September 1971 the Remote Sensing Laboratory was formed within Iowa Geological Survey to coordinate remote sensing activities in the State of Iowa. Remote Sensing Laboratory staff within IGS analyzed the imagery acquired in June 1971 and developed thermal maps for portions of the river from Clinton to Keokuk, Iowa.

An uncalibrated scanner, mounted in the Twin Beechcraft from the Remote Sensing Institute, was used for the June mission. The unclibrated scanner from the Remote Sensing Institute utilized the 4.5 to 5.5 micron portion of the infrared spectrum and thermal data was recorded, in flight, directly on film. A Barnes PRT-5 radiometer tracked nadir below the aircraft but was not roll compensated with the scanner. The June mission was flown at or near noon and thus both the heating effects of the sun and reflective effects of radiation at near infrared wavelengths were detected. Although the mission design was not optimal for thermal mapping purposes, analysis of thermal imagery revealed that valuable information was derivable from the imagery, particularly for purposes of monitoring systems design.

The Iowa State Conservation Commission, State Hygienic Laboratory, Iowa Attorney General's Office, and U.S.Geological Survey, Water Resources Division, were informed of the mission and they provided assistance in the form of manpower, boats, and equipment. The U.S.Army Corps of Engineers, Rock Island, were informed and they agreed to maintain the stage of the river as constant as possible during the mission.

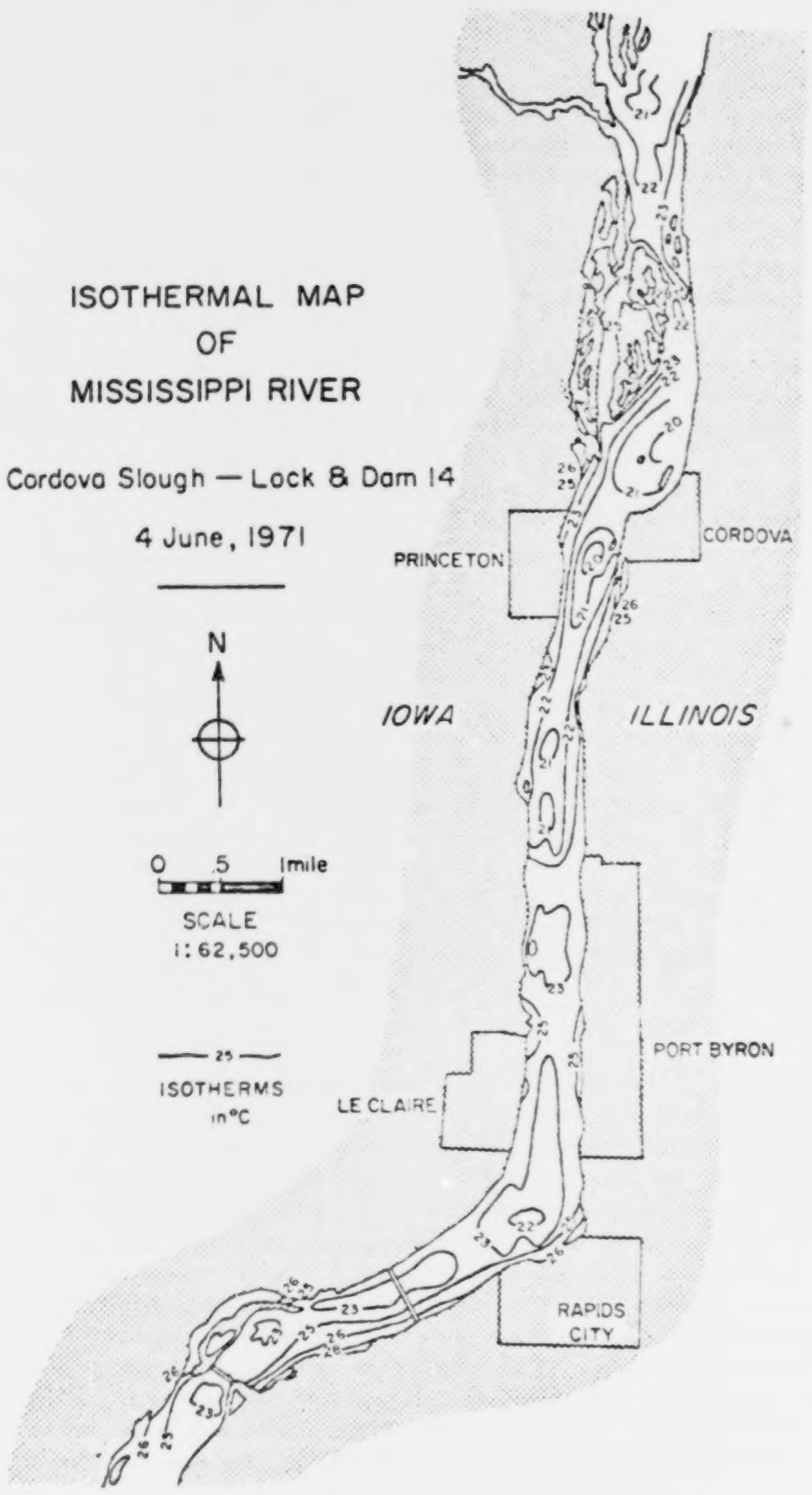
Thirteen ground data acquisition teams, on the June 1971 mission, obtained records of ground conditions as they existed at the time of the overflight. This data is required to identify and quantify the images obtained by the multispectral camera and infrared scanner. These teams were assigned cross-channel traverses spaced along the 180-mile length of river from the Commonwealth plant site to Keokuk. The three-man teams consisted of personnel from the Iowa State Conservation Commission, the Iowa Geological Survey, and U.S.Geological Survey, and representatives of Commonwealth Edison. Boats were provided by the Conservation Commission and water-sampling kits were distributed through the State Hygienic Laboratory. Mobilization of this large ground data collection effort was accomplished in a short period of time, with no direct project expense involved.

The thirteen ground information stations were located to sample a variety of river conditions, such as single-channel areas, multiple channel areas, backwater sloughs, urban areas, proximity to locks and dams, and incoming tributary drainage. Along the route of each open river traverse, a minimum of five temperature-sampling points were designated. These points were established in relation to some recognizable island or landmark. Each team was on the river from 0900 hours until 1600 hours making traverses across the river channel. Teams had certified thermometers for recording surface water temperatures. Thermometers were held completely immersed, parallel to and just beneath the water surface. Air temperatures were also taken at the beginning and end of each traverse. Ground teams recorded 874 temperature readings from 117 sample points along the 13 traverses and the ground data represents the most comprehensive compilation of water temperatures and climatological information ever amassed in a given time period on the Mississippi River.

On 4 June 1971 arrangements were made for two coverages of the study area at 10,000 feet above ground level and one at 3,000 feet. When the mission was actually flown a third level at 6,000 feet was added. Imagery from the first flight at 10,000 feet was not satisfactory due to cloud cover. The second flight was flown at 2,850 feet from Keokuk to Clinton. Some clouds appear on all imagery. The 6,000 foot imagery was flown when the cloud problem abated and this imagery was the best acquired during the June 1971 mission.

Imagery was analyzed by both visual means and automated electronic density slicing. The visual evaluation of the thermal imagery was conducted using a Richards light table and microscope. Thermal outfalls were noted and traced to their respective sources. Analysis showed that during June, rivers flowing into the Mississippi are generally hotter than the main channel water by several degrees. The thermal outfalls from the Muscatine and Riverside electric power generating plants were at least 10°F hotter than the channel water and their plumes extended at least one quarter mile downstream. Slough areas were particularly hot owing to their relatively static condition. Islands in the river were relatively hot and long sinuous plumes from these islands often extended as much as one mile downstream. The thermal technique mapped surface current distribution patterns in the river with remarkable accuracy. These patterns indicate areas of slow moving water, the thalweg of the main channel, and areas of rapid moving water. Areas of slow moving water are not subjected to the turbulent flow present in the main channel and the outside loops of meanders. Therefore slow moving water areas appear warmer because the water heated by the sun is not mixed with colder water stratified below. By identifying areas of rapid flowing water, slow moving water, and almost static water, and relating these areas to the geometry of the river system, distribution patterns in the river are identified. The streaming effect from islands, tributary drainage, and shallow areas is analogous to the streaming effect observed by placing dye in a river system model. Although the original mission was designed to evaluate thermal discharges in the river and to sample the thermal regimen of the system, the major information derived from this study was information on surface current distribution. This type of information could be essential for the development of spill removal plans, but even more significantly it could provide information for the placement of monitoring instrumentation.

Automated analysis was performed on the thermal imagery to produce an isothermal map. The original film transparencies, obtained during the overflight, were used for this analysis. Film density is directly related to the energy received by the scanner, and equal film densities represent equal temperature levels on thermal imagery. By correlating known surface water temperatures with film densities, point data can be extrapolated and isotherms established without the element of human interpretation involved. Film sections were analyzed on an electronic television density analysis device. This apparatus consists of a light source, film holder, television camera, density digitizing and coloring electronics, and a television camera. Color encoded isodensity mosaics were produced covering 74 miles of river. The relationship between temperature and density was not well defined. The discrepancy in relating temperature to density may be a function of the thermal scanning equipment itself. The scanner used on the June mission was not internally calibrated and utilized the 3 to 5 micron band. No reference



ISOTHERMAL MAP OF MISSISSIPPI
4 JUNE 1971

temperature was built into the system so that it might recalibrate itself. With time and possible associated internal changes, the scanner response may change slowly. Atmospheric conditions may also account for the imaging differences and particularly atmospheric humidity may vary downstream. The scanner operated in the 4.5 to 5.5 micron range of the electromagnetic spectrum. This range is particularly susceptible to atmospheric effects and even partially recordes reflected solar radiation.

A serious problem resulted because most of the recorded temperatures were obtained within a small temperature range. Few known points were available at higher temperatures to determine the temperature-density relationships.

While the most important results of this study are qualitative, the semiquantitative analysis does show that an accurate quantitative map of river temperature is possible with some refinements of technique and with use of proper equipment. Imagery was obtained with a 4.5 to 5.5 micron scanner, close to noon, and emitted radiation plus reflected radiation was detected and mapped. The thermal scanner was not calibrated and thus instrument drift could not be assessed. Ther was no way of obtaining an exact trace of the PRT-5 radiometer track. Ground temperature measurements did not correspond to the time of the actual overflight. Ground temperatures concentrated almost exclusively on main channel temperatures, thus creating a density of calibration points near one temperature but few points from which to construct a relationship between temperature and density. Water temperature measurements were made close to shore, dams, or bridges and thus the instantaneous field of view of the scanner incorportated temperatures of these features as well as that of the river water.

In spite of the numerous problems identified this study, it was established that airborne remote thermal mapping of a large river system is a considerable economy, in terms of time and money, over the acquisition of conventional point data. Remotely sensed thermal data can be acquired over hundreds of miles of river in a single day, using only a small number of ground personnel and a limited amount of equipment. Quantitative results can be obtained if proper mission design is executed. Mission design should include a blackbody reference calibrated scanner operating in the 8 to 14 micron range of the electromagnetic spectrum, preferably with the two references set at the high and low ends of the temperature scale, and with an aircraft mounted PRT-5 radiometer trace electronically located on the scanner imagery. The scanner, airborne PRT-5 radiometer, and ground PRT-5 radiometers should be calibrated simultaneously before and after the mission. Good analytical results are obtained for missions flown over river systems at an altitude of 3,000 feet to 6,000 feet above river level. To properly evaluate thermal regimen of a river system, the mission should be flown twice during the day, at noon to assess the heating effects of the sun, and after sunset but before fog sets in, to assess the heating effects due primarily to manmade sources. Ground information teams should measure river temperatures with portable radiation thermometers (which measure radiant spectral emittance 8-14 microns), and with vertical probe strings inserted at varying depths in the river. Air temperature, humidity, wind velocity and direction, and climatological phenomena should be recorded at the instant the aircraft passes overhead, and these variables should be assessed during the entire mission. General weather conditions should be observed for one week prior to the mission.

VISUAL MAPPING TO IDENTIFY SOURCES OF THERMAL EFFLUENT ON THE MISSISSIPPI

A low-altitude reconnaissance flight was flown on 14 February 1972 to make a visual and photographic record of all open water areas on the Mississippi River between Keokuk, Iowa and the Iowa-Minnesota border. The purpose of the survey was to identify points on the river at which warm effluents are being discharged. The behavior of water during icing is such that open water can result from three significantly different conditions:

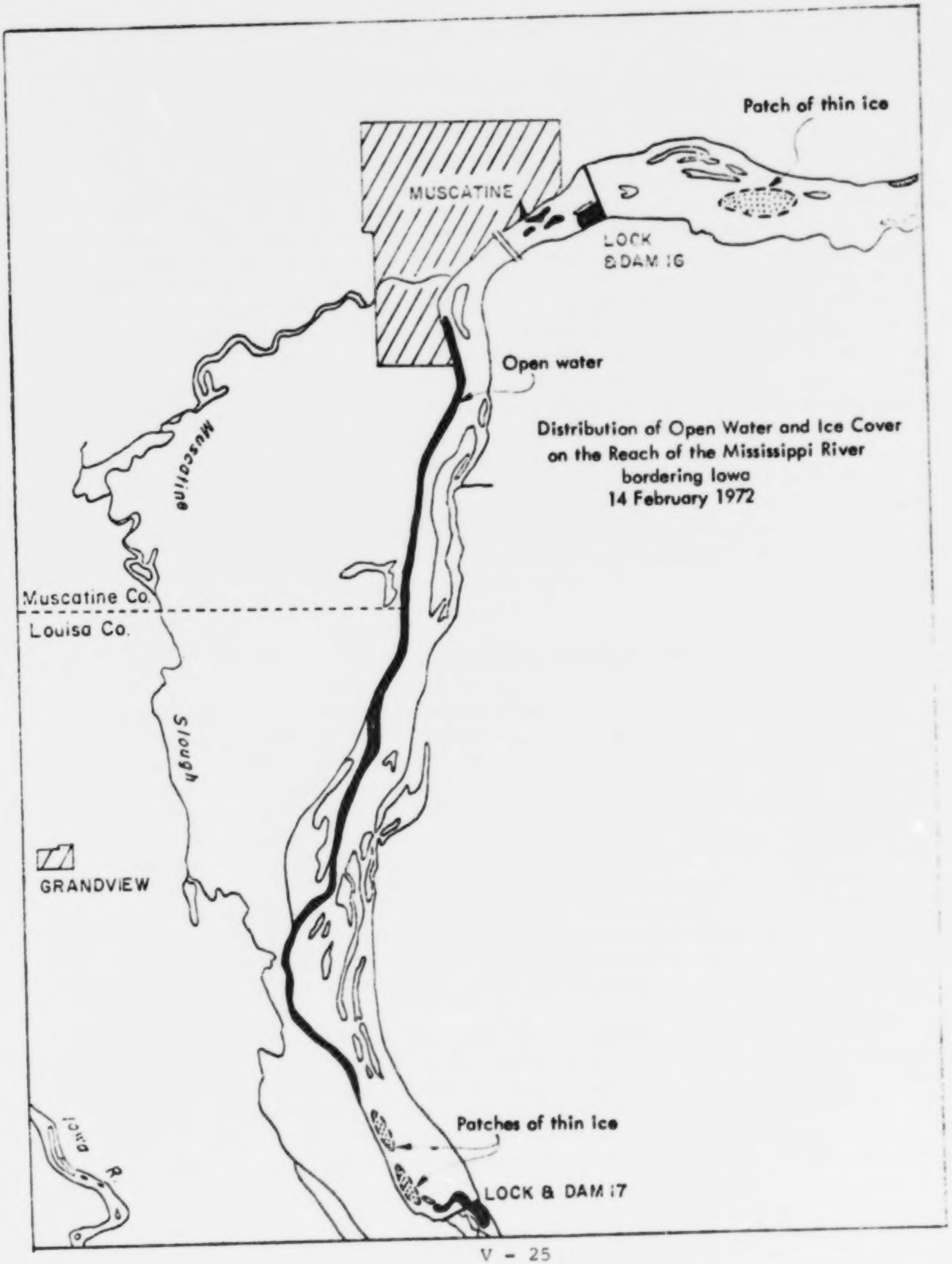
1. First is the obvious condition of imputs of water sufficiently above the temperature of 0°C that loss of heat to the atmosphere is not at a rate high enough to cause ice to form at the point of input and/or downstream for significant distance. This type of imput could have three types of sources in the Mississippi River in Iowa;

   a. Industrial, municipal and/or domestic outfalls,
   b. Discharges of groundwater, and
   c. Upwelling of warmer bottom waters below dams.

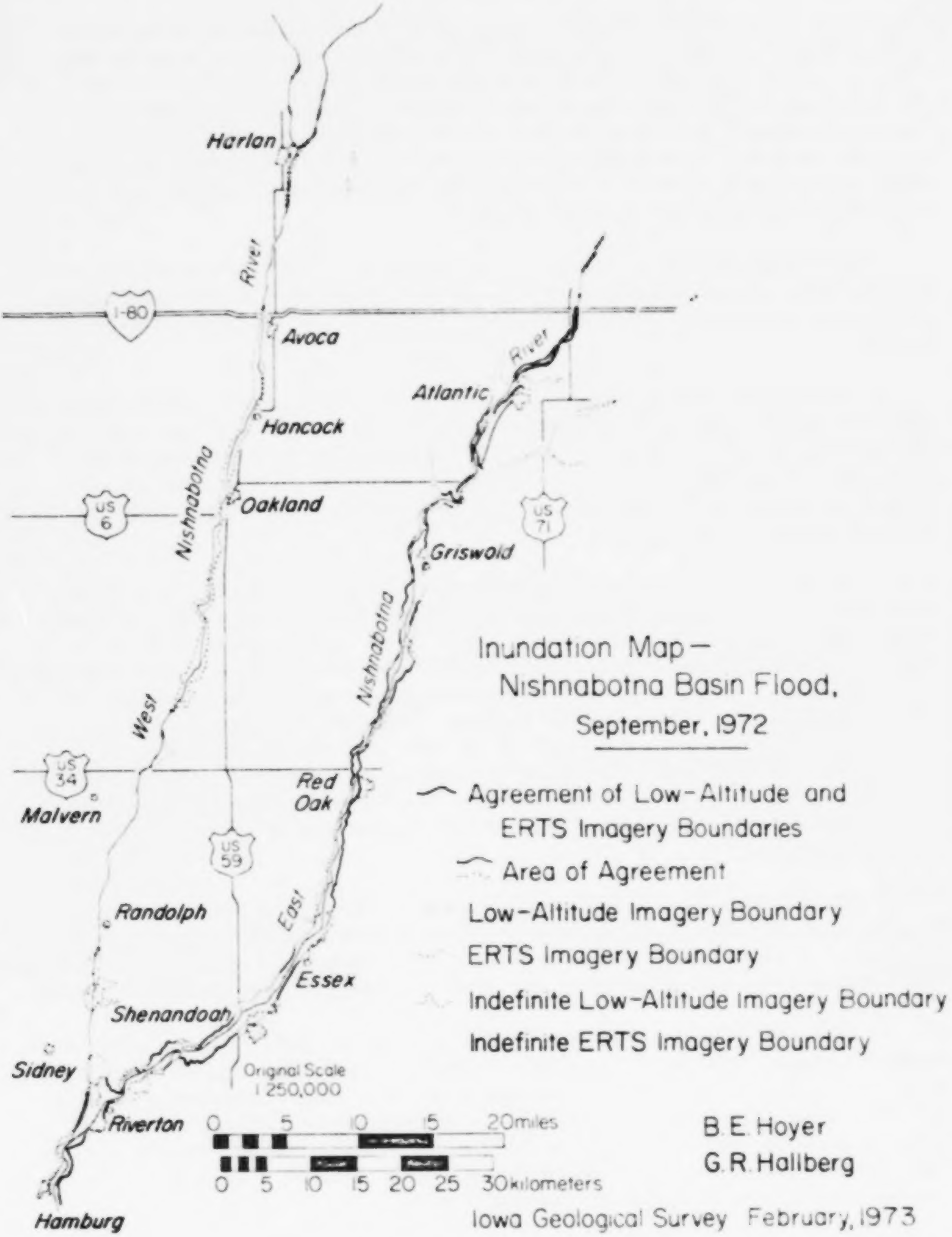
2. The second condition that account for open water is turbulence of flow. The occurrence of these conditions can be definitely recognized in the Mississippi River bordering Iowa only below dams that are set as weirs. Open water between dams that has no physically traceable source to hot-water outfall may be the result of upwelling warmer bottom flow or purely the result of turbulence where elements of the current converge. More likely, they result from a combination of both turbulence and melting.

3. The third circumstance that accounts for open water during icing conditions is physical disturbance of the ice layer, like that caused by an icebreaker.

The visual and photographic reconnaissance was accomplished by utilizing the Iowa State Conservation Commission aircraft and a hand-held 35 mm camera. The date in February was selected because prior to that time temperatures in the area had been continuously below freezing. Twenty-seven major open water stretches were detected on the Mississippi River as it borders Iowa, even though temperatures ranged below zero for almost 20 days prior to the overflight. Ten sources were directly related to open water below dams, while seventeen sources were traced directly to industrial and/or municipal outfalls. Four of these seventeen sources emanated from the Wisconsin side, one from the Illinois side exclusively and one from the Illinois side in part. Examination of atmospheric data indicates that the amounts of heated effluent being discharged at 12 of the sources must have been very significant and at the balance significant in any evaluation of the unnatural elements of the thermal regimen of the reach of the Mississippi River bordering Iowa.



Distribution of Open Water and Ice Cover on the Reach of the Mississippi River bordering Iowa 14 February 1972


Inundation Map — Nishnabotna Basin Flood, September, 1972
Agreement of Low-Altitude and ERTS Imagery Boundaries
Area of Agreement
Low-Altitude Imagery Boundary
ERTS Imagery Boundary
Indefinite Low-Altitude Imagery Boundary
Indefinite ERTS Imagery Boundary
Harlan
River
I-80
Avoca
Hancock
Atlantic
River
Oakland
US 6
US 71
Griswold
Nishnabotna
Nishnabotna
West
US 34
Malvern
Red Oak
US 59
Randolph
East
Essex
Shenandoah
Sidney
Riverton
Hamburg
Original Scale 1:250,000
0 5 10 15 20 miles
0 5 10 15 20 25 30 kilometers
B. E. Hoyer
G. R. Hallberg
Iowa Geological Survey February, 1973

flood crest. Maps of the inundated area were prepared by interpretation of the various types of imagery and all known ground data agree with this mapping. In early January, 1973, an ice jam developed at the lower end of the Iowa River and artifically raised the river stage until the water flowed onto the adjacent floodplain. The flooded area was readily apparent to airborne observers as it remained as smooth ice surrounded by rough ice and snow. The last flood analyzed was a spring flood along the Skunk River, which occurred on 23 April 1973. The Skunk River experienced the greatest flood on record following heavy rains on saturated ground.

Iowa Geological Survey, Remote Sensing Laboratory staff utilized a multiband camera, metric camera, and hand-held cameras with a variety of film filter combinations to map these three floods. The following conclusions summarize the results of these studies.

1. Photographic infrared radiation is by far the most important and useful spectral region for mapping floods either after flood cessation or concurrent with flood crest. The characteristics of infrared radiation, including the absorption of these wavelengths by water, the reduced infrared reflectance of wet soils and stressed plant species and differences in reflectance between snow and ice, make the infrared band the most useful for flood inundation mapping.

2. The addition of color aids the interpretation in both the visible and near-visible wavelengths. Black-and-white panchromatic films are generally unacceptable for flood mapping and color films are generally better in the visible portions of the spectrum. Black-and-white infrared film may produce a usable product for mapping flood inundation, but color infrared film is superior. For multiseasonal flood mapping, especially for late summer flood mapping, color infrared film (Kodak 2443) seems to be the best available film. Multispectral imagery, combined with color additive viewing techniques, is actually the best approach for flood inundation mapping. However data handling problems, smaller areal coverages of the multiband camera, and the information needs of agencies involved in floodplain management make multiband imagery less desirable than color infrared imagery.

3. Stereoscopic viewing aids flood mapping especially in areas in which interpretation based on color or tone is difficult. Proper overlap should be provided to allow stereoscopic viewing and to allow photogrammetric operations such as topographic map production. This could provide data useful for engineers and persons in floodplain management and planning.

4. ERTS satellite data supports the conclusions of the low-altitude studies. Evaluation of ERTS-1 imagery indicates that it is useful for small-scale, regional flood inundation mapping. The synoptic coverage of ERTS imagery allows rapid regional appraisal of flooding. This may be particularly useful for agencies involved in regional flood control, disaster relief, agricultural crop prediction, and flood insurance. Its mapping capability may provide a first approximation of flood inundation especially useful for large areas, and in sparsely settled, poorly mapped, or inaccessible areas.

5. The detailed mapping of inundation from large-scale imagery indicates a close correlation between large magnitude floods and particular soil series. Further analysis may allow the quantification of soils in terms of the frequency, magnitude, and distribution of floods. This, in turn, may possibly provide the capability for the detailed flood inundation prediction required for rational landuse planning.

6. This aerial technique allows flood inundation to be mapped a minimum of seven days after flood crest in late summer, and at least five days after flood recession in spring. Winter flooding could be mapped in at least these time periods.

7. The recommended techniques indicated by these studies should provide more detailed data for flood inundation mapping in a more cost-effective manner. Generally, flood inundation mapping is best accomplished with color infrared film (Kodak 2443) filtered to eliminate blue wavelengths (Wratten 12 filter), and exposed in a metric aerial camera. Imagery should be acquired as soon as weather conditions permit, after flood recession. Sufficient overlap should be included to provide complete stereoscopic imagery both for interpretation and for photogrammetric purposes. The scale of the imagery must be carefully determined from the potential imagery uses and the extend of flooding.

USE OF REMOTE SENSING DATA FOR FLOODPLAIN MANAGEMENT-PLANNING AND FOR MONITORING SYSTEMS DESIGN

Low altitude multispectral imagery of flood inundation in three seasons has indicated a close correlation between particular soil series and inundation boundaries of major floods. Detailed analysis of low altitude imagery coupled with comprehensive soils mapping appears to yield information on the nature and extent of the floodplain. Preliminary analysis has revealed that it may be possible to quantify particular soils in terms of the frequency, magnitude, and distribution of floods which affect them. Analysis of this kind could produce an operational definition of what constitutes the floodplain for landuse planning purposes. An accurate definition of the floodplain is required, particularly for locating sanitary landfills, granting of permits for feedlots and sewage lagoons, and for liquid and solid waste management.

Another aspect of low altitude multispectral photography of the floodplain was the synoptic coverage of existing petroleum, chemical, and other industrial liquids in tank farms and storage lagoons on the floodplain. Runoff over feedlot operations could be traced into small drainages, and eventually into some major rivers. Therefore it seems possible to designate the location of ground monitoring instrumentation from a single photographic overflight. Further, along the Mississippi River, analysis of photography not only located major liquid storage facilities but also yielded information on the nature of berms and dikes surrounding these facilities. Should major flooding, fire, or other disasters damage tanks or ponds, and thereby allow pollutants to enter hydrologic systems, strategically placed monitoring instrumentation could detect pollutants early enough to perhaps allow their efficient removal. When pollutants are detected by strategically located ground instrumentation, a remote sensing overflight could be arranged to map the geometry of the spill. This information could be utilized to coordinate emergency removal procedures and document possible violations. Again, highly repetitive, and thus expensive, airborne remote sensing overflights would not be required for the development of a river-floodplain monitoring system.

CONCLUSIONS

An understanding of the surface current flow characteristics, channel geometry, natural thermal regimen, extent and characteristics of the floodplain surrounding a major river, coupled with information on the location of thermal sources, location of major outfalls from treatment facilities, industries and agricultural land, and location of liquid storage facilities could provide information for the development of a comprehensive floodplain and river monitoring system. A single remote sensing thermal and photographic overflight can provide information for the strategic location of ground instrumentation. This ground instrumentation can detect anomalous concentrations of pollutants and alert monitoring personnel so additional remote sensing missions could be arranged to trace pollutants to their sources. In this manner ground instrumentation could be efficiently located and redundancy in placement avoided. At the same time, highly repetitive, redundant, and thus expensive, airborne remote sensing overflights can be minimized.

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TECHNIQUES AND PROCEDURES FOR QUANTITATIVE WATER SURFACE TEMPERATURE SURVEYS USING AIRBORNE SENSORS

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I. INTRODUCTION

The NASA Johnson Space Center's Earth Resources Laboratory (ERL) located at the Mississippi Test Facility has as part of its responsibility the development and demonstration of remote sensing techniques and procedures that lend themselves to describing, evaluating or quantifying our natural resources and the state or condition of our environment. Water characteristics are basic parameters of our environment and a key measurement related to the condition of the water is temperature. Airborne remote sensing techniques for water surveys, with their ability to cover large areas quickly, have a number of potential applications. An obvious use is the location and measurement of outflows that are at a different temperature than the receiving body of water (rivers, lakes, etc.). Temperature surveys are also a routine part of practically all oceanographic studies and provide useful information for marine resource habitat assessment in coastal waters and estuaries.

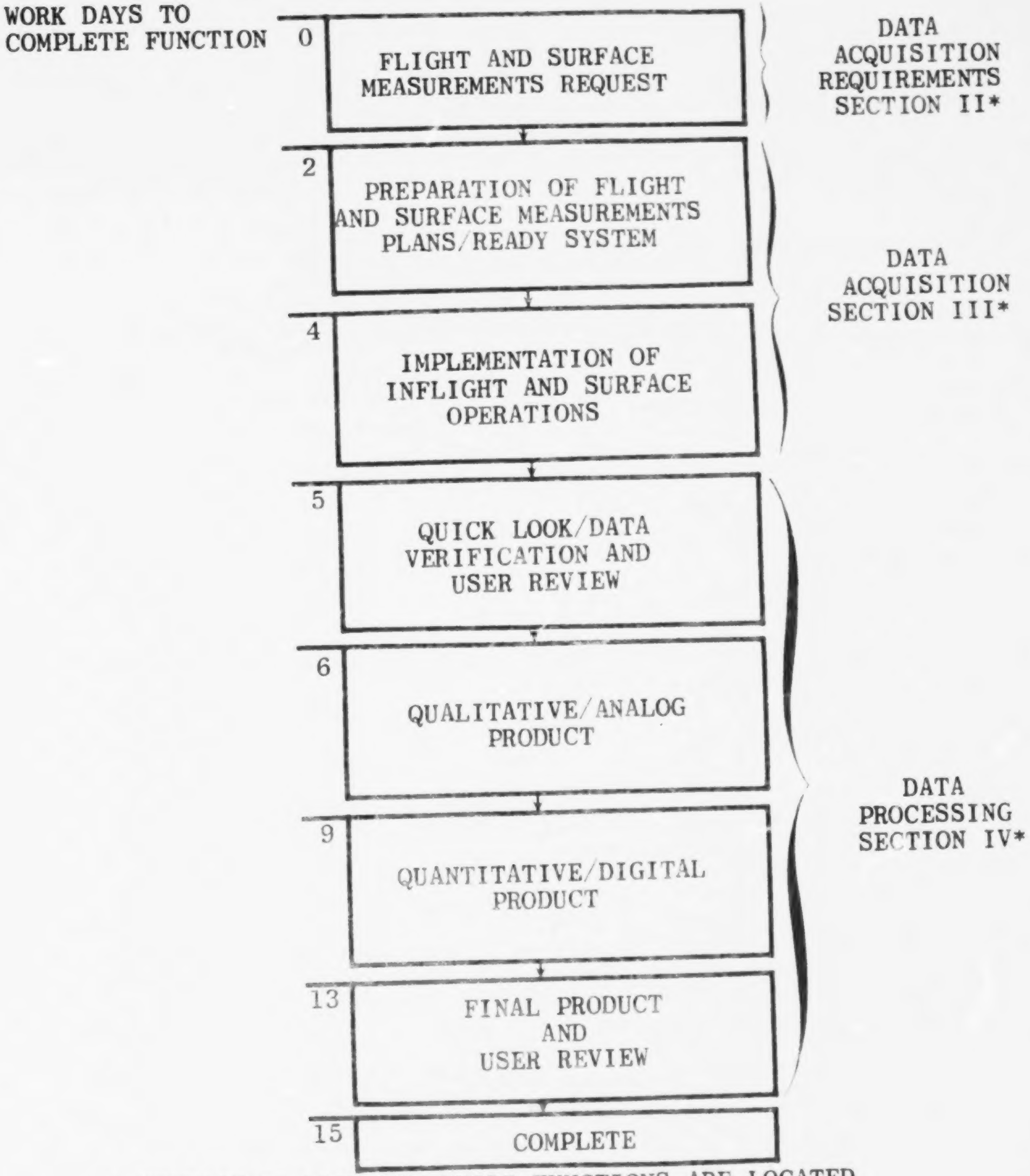
In the past, large area temperature surveys have been conducted using portable and stationary insitu instruments. However, the data collected is usually not synoptic and the cost is great. During the past several years remote sensing techniques have made it possible to obtain large area surface temperature data on a qualitative basis at relatively small expense. Recently, these remote techniques have been improved to allow the quantitative measurement of water surface temperature on a routine basis with consistent reliability and accuracy. The purpose of this paper is to describe the procedures, and the techniques on which they are based, for a user to properly plan and conduct a quantitative survey of surface water temperature.

Procedures and techniques described here for remote sensing thermal properties of water are those used at ERL and are based primarily upon a series of experiments (Ref. 1) performed in the Mississippi Sound during 1972 using a Texas Instruments RS-18 airborne thermal scanning radiometer, hereafter referred to as the scanner or thermal scanner, mounted in a light aircraft. (Ref. 7) However, the procedures described should be adaptable to other data acquisition and processing equipments and may be used with high altitude aircraft and satellite data.

This paper is a condensed version of a detailed ERL report (Ref. 2) on techniques and procedures in which each step is supported by discussion and/or appendices which present hardware and/or software descriptions, specific procedures, or descriptions and examples of forms. It is assumed here that the hardware and software required to carry out the steps in the survey are available and checked out. The major elements of the hardware and software systems are shown in Figure 1. The remainder of the paper describes in general the steps, as illustrated in Figure 2, which are required to plan and conduct the temperature survey.

DATA ACQUISITION	THERMAL SCANNING RADIOMETER LABORATORY AND AIRBORNE CALIBRATION SOURCES SCANNER PLATFORM (AIRCRAFT OR SATELLITE) AND DATA RECORDING SYSTEM
DATA VERIFICATION/ QUALITATIVE PRODUCT	TAPEDECK AND OSCILLOGRAPH TAPE TO FILM CONVERTER PHOTO PROCESSING FACILITY
QUANTITATIVE PRODUCT	ANALOG TO DIGITAL CONVERSION- SDS930 COMPUTER AND SOFTWARE DATA PROCESSING-UNIVAC 1108 COMPUTER AND SOFTWARE DISPLAY PREPARATION-SC4020 PLOTTER AND SOFTWARE

FIGURE 1. MAJOR HARDWARE AND SOFTWARE ELEMENTS


WORK DAYS TO COMPLETE FUNCTION
0
FLIGHT AND SURFACE MEASUREMENTS REQUEST
2
PREPARATION OF FLIGHT AND SURFACE MEASUREMENTS PLANS/READY SYSTEM
4
IMPLEMENTATION OF INFLIGHT AND SURFACE OPERATIONS
5
QUICK LOOK/DATA VERIFICATION AND USER REVIEW
6
QUALITATIVE/ANALOG PRODUCT
9
QUANTITATIVE/DIGITAL PRODUCT
13
FINAL PRODUCT AND USER REVIEW
15
COMPLETE
DATA ACQUISITION REQUIREMENTS SECTION II*
DATA ACQUISITION SECTION III*
DATA PROCESSING SECTION IV*

* SECTION OF DOCUMENT WHERE FUNCTIONS ARE LOCATED.

TEMPERATURE SURVEY SCHEDULE AND FLOW DIAGRAM

FIGURE 2

II. DATA ACQUISITION REQUIREMENTS

A. General

Development of data acquisition requirements is the first step to be performed in planning for a surface water temperature survey as indicated in Fig. 2. The following discussions comment on the methods used by ERL in the planning process to establish requirements and determine most of the factors to be considered in order to optimize the acquired data for the intended use.

B. Flight and Surface Measurement Requirements Documents

The Mission or Survey Flight and Surface Measurement Requests are documents (forms) initiated and filled in by the data user. They serve as documents that delineate the objectives and all requirements of the survey to all participants. These request forms include: project name, user name, data acquisition date, flight and surface requirements and constraints, communications, sensor and calibrations requirements.

C. Data Optimization through Choice of Flight Conditions

During preparation for a data acquisition flight with the thermal scanner several conditions under which the data is taken should be considered to optimize the data as much as possible. The conditions to be chosen for the flight are somewhat dependent on the purpose for which the data is being taken as noted in the following discussion.

1. Time of Day - Since the signal detected and recorded by the scanner system is a function of emitted and not reflected solar energy, thermal measurements may be taken any time of the day or night. However, two factors should be considered in the choice of flight time; one is cloud cover and the other is land/water differentiation.

Cloud cover above the aircraft normally is not a direct consideration when recording remote thermal data. Indirectly it can be a consideration if the purpose of the data is to study short term water surface characteristics such as insolation. However, in most cases a more serious concern is cloud cover below the aircraft. Since clouds are opaque to radiation in the thermal region those surface areas covered by clouds cannot be surveyed. Therefore, the choice of flight time should be made by considering the normal weather patterns of the area. For example, weather conditions in the coastal areas along the Gulf of Mexico are such that the waters just off-shore are usually free of clouds in the morning in the summer time. In addition, the amount of cloud cover is important. If one wishes to measure gross features of surface temperature distribution, 50% cloud cover below the aircraft is probably an acceptable condition. However, if one is looking for specific detailed thermal patterns or requires the measurements in a specific area cloud cover requirements should be 0 - 10%. Cloud cover in excess of 50% is usually not acceptable because of the difficulty in making atmospheric corrections to the data and because the scanner detector has a time constant which does not allow an adequate signal recovery when the field of view passes from the cold cloud top temperatures to the water surface temperatures in the small cloud free areas.

The second area of consideration is the differentiation of land/water interface. In areas such as marsh where the land and water areas form complicated patterns one may rely on the thermal imagery to determine the location of data, i.e. in cases where aerial photography is not acquired with the thermal imagery for data location and no navigation information is available. At certain periods of the day and night land and water surface radiometric temperatures approach each other and may be indistinguishable in the thermal imagery. This can occur during a time when lighting conditions do not make aerial photography possible such as twilight or early morning and, therefore, such times should be avoided to the extent possible.

In some cases time of day for the flight may be fixed by other considerations such as surface conditions, requirements for thermal data correlation with other sources of data or by operational constraints. For example, in coastal waters, flights are sometimes scheduled for particular tidal conditions. Unplanned events such as fish kills may be the object of an investigation requiring data collection under non-optimum conditions. Another consideration may be the availability of surface measurements for scanner calibration. In larger bodies of water high sea state may sometimes limit this availability if small boats are involved. However, this is usually a minor constraint for remote thermal measurements since only one boat is required for relatively small areas.

2. Flight Line Determination - Once the time of day is chosen the flight line determination must be made. If the survey area can be covered by one flight line the altitude of the aircraft is usually set such that the scanner field of view covers the area with some additional coverage on the sides of the scan to account for navigation error. If the area is large, one must cover the area with parallel flight lines again allowing an overlap with the adjacent flight line to account for navigation error. Typical overlap is 20%. In this case the aircraft altitude is usually kept as high as practical to maximize coverage and reduce the number of flight line miles. This is done for both economy reasons and to make the entire data set as synoptic as possible. Synoptic data is particularly important when studying dynamic surface conditions.

A significant consideration in flight line planning is that of navigation. For large geographic areas requiring multiple flight lines an automatic navigation system is most desirable. However, this type of navigation is frequently not available and one must resort to visual navigation using surface landmarks. Under these conditions one must pay attention to flight line layout to make the navigation task as simple as possible for the pilot. For large bodies of water, for instance, the preferred technique is to lay out parallel flight lines perpendicular to the shore so that shoreline landmarks may be used for navigation and in addition to serve as an aid in location identification using photography and scanner imagery during data verification and analysis. In areas such as marsh where no distinguishable landmarks are available one may resort to deploying artificial landmarks for navigation. If navigation aids such as radio beacons are available one should lay out the flight lines to take maximum advantage of these. Unless lighting conditions prohibit, high resolution aerial photography is usually taken simultaneously and time correlated with the scanner data to provide a means of data location during data reduction and analysis. Sun angle (time of day) may then become a factor in choice of flight ime.

Prevailing wind direction and velocity may also be a factor in flight planning for two reasons. First, a cross wind at flight altitude can cause an aircraft crab angle resulting in skew in the scanner imagery. This may be corrected during digital processing but is difficult because the crab angle usually varies during flight. Crab angle of less than 5^o is usually acceptable without correction. Cross winds also make navigation difficult when no or only simple navigation aids are available.

The second reason for considering wind during flight planning is the necessity for maintaining constant ground speed when flying flight lines. Changes in ground speed cause changes in scale in the scanner imagery and introduce an additional complication in data analysis, especially when data acquired on parallel, adjacent flight lines in different flight directions are to be compared or a large area thermal contour map is to be constructed from the data.

III. DATA ACQUISITION

The ERL thermal survey data acquisition equipment consists of a thermal scanner and data recording system mounted in a Beech Model E-18 twin engine light aircraft. A block diagram of the system is presented in Figure 3.

A. Data Acquisition Preparation

1. Mission or Survey Flight Plan

The mission or survey flight plan parallels the same general outline as the mission flight and surface measurement requests. It is developed to provide additional information for the guidance of the flight crew presenting priorities and details relative to flight lines.

The information specifically covered in the document includes:

- Flight objective
- Sensor requirements
- Flight requirements
- Flight line priority
- Communications (radio)
- Mission constraints
- Flight schedule (timeline)
- Flight line requirements
- Flight line map.

The surface measurements request for boat operations is used also as the surface measurements plan; therefore, no parallel document to the flight plan is needed for most surveys.

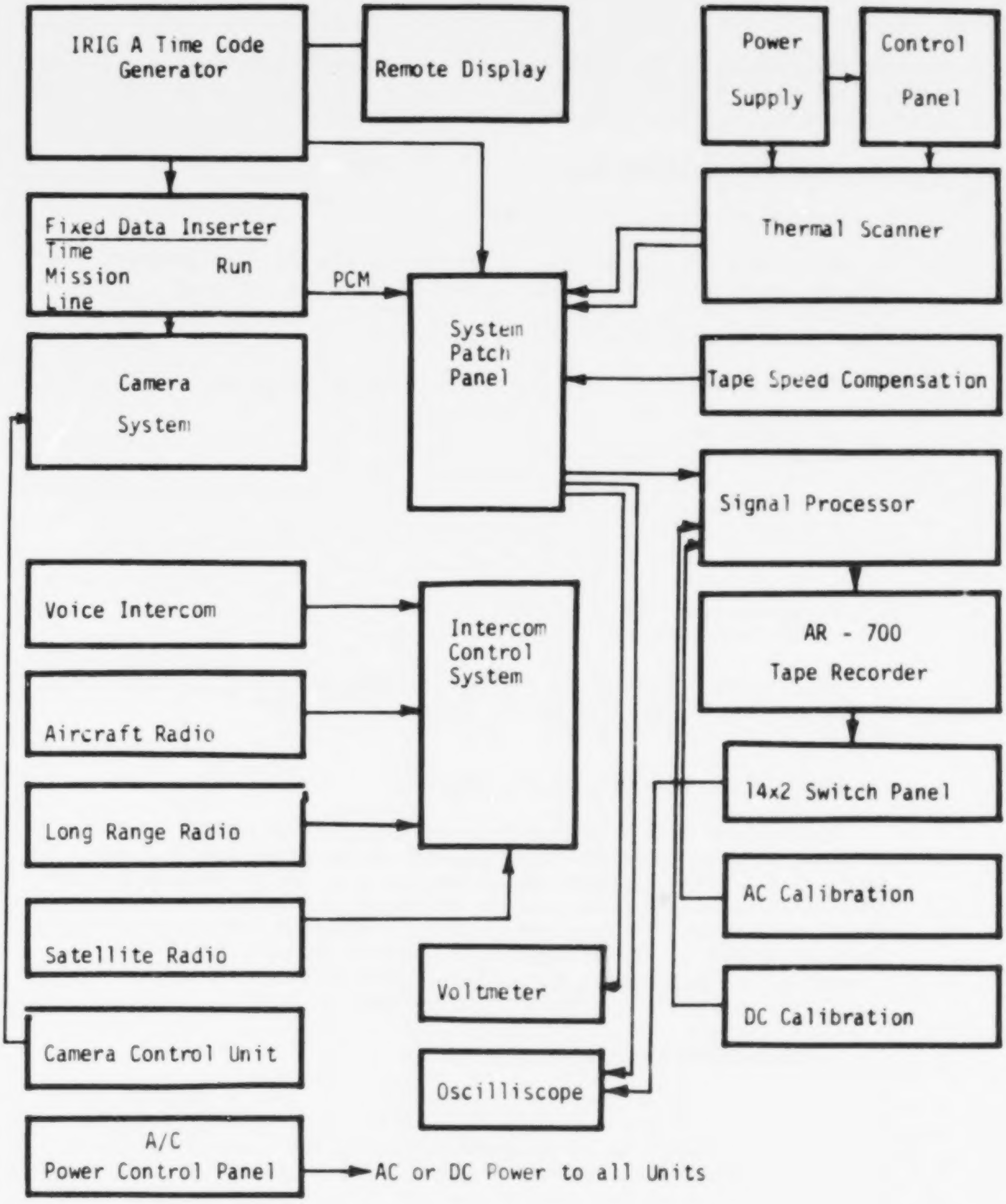
2. Calibration and Checkout of System

The scanner equipment manufacturer includes system calibration and checkout procedures in the operation and maintenance manual. (Ref. 5) However, it is usually more desirable for the user to develop his own procedures for a particular system using the operation and maintenance manual as a guide. Such a procedure is utilized by ERL on a periodic basis to assure proper performance of the equipment. After the lab procedures are performed, the system is installed in the aircraft and a pre-survey checkout is performed before each flight.

3. Other Preparation Activities

Prior to performing a survey the pilot must file an appropriate flight plan that meets requirements of the FAA officials in the survey area. The plan must be in accordance with flight lines to be flown during the survey. A weather forecast or status should be obtained from the National Weather Service for the survey area prior to flight time to assure that meteorological conditions are within constraints specified in the Survey Flight Request and Surface Measurements Request.

The camera system selected for the survey should be installed in the aircraft with the proper film filters, framing rate (overlap), and



Block Diagram
ERL AIRCRAFT THERMAL SCANNER AND DATA RECORDING SYSTEM

FIGURE 3.

boresighted to the scanner field of view to meet the photographic documentation requirements and lighting conditions during the survey.

B. Data Acquisition Implementation

During the implementation phase of data acquisition the primary objective is to acquire usable data that meets the requirements of the flight and surface measurement plans. The following paragraphs discuss the activities which take place during the flight and surface operation.

1. Communications required for a survey depend on the complexity of the acquisition activities and the ability of the boat and flight crews to follow plans developed for the survey. Generally, a radio communications link is not required between the surface measurement boat and aircraft crew unless problems are encountered during the flight. If real time communications are used planning should include the designation of the radio frequency on which the crews will be operating.

2. Navigation

Scanner data spatial quality is influenced by how well the aircraft follows the designated flight line. That is to say, the desired goal is to go from point "A" to point "B" in a straight line with a minimum of aircraft maneuvering. The success one can expect in achieving the goal is a direct function of the sophistication in aircraft navigation systems. The three levels of navigation one can encounter are:

a. Dead reckoning
b. Homing beacon - automatic direction finding
c. Inertial navigation system - auto pilot control

Dead reckoning requires that the pilot be familiar with flight line requirements (lines on maps or photos) and be able to translate these requirements into a real time flight path. Results may vary to a minor extent depending on the pilot's experience. A homing beacon is an electronic assist to the pilot since it allows him to direct the aircraft to or from a known fixed point. Accuracy in flying straight lines is improved with the assistance of this equipment, but the homing beacon is most useful for single flight lines. The inertial navigation system is the ultimate in flight avionics but as such is the most expensive. Using this automatic navigation equipment, position accuracy greatly increases and the aircraft is auto-piloted in a straight line (large maneuvers are suppressed) and also the craft can be steered accurately on successive parallel lines.

Because of the inherent cost of the inertial navigation system it is seldom encountered except in the largest of flight programs. Most activities use dead reckoning or homing devices and as such live with the degree of compromise these methods require.

3. Camera Operation

Photographic documentation should be gathered whenever the thermal scanner is gathering data on a flight line for later documentation and data location purposes. For altitudes below 10,000 feet a 70mm film format with 4[illegible]mm lens has been found adequate for most purposes. For open water work where the location of small objects such as buoys is necessary for data locations a larger film format or longer focal length lens may be necessary. Film type may be dependent on other user requirements but color infrared has been used primarily by ERL because of its insensitivity to atmospheric haze and its enhancement of surface features. However, color infrared film may not be acceptable when poor lighting conditions prevail because of its relatively slow speed.

4. Thermal Scanner Operation

Inflight operation of the thermal scanner requires that the system be allowed at least a ten minute warm up period prior to acquiring data on the first flight line. The roll correction gyro must be erect to prevent skewing of the imagery and the thermal scanner gain control must be adjusted over water in the surver area rather than land to obtain maximum signal range of surface water radiometric temperature. Procedures for the operation of the thermal scanner are given in Ref. 2.

5. Flight Logs

The flight logs are a necessary form for record keeping, so that important flight information is preserved for future reference. Parameters recorded on the logs figure prominently in subsequent data processing for determination of start and stop times, for recording gain settings, calibration, voltage times and levels, air and ground speed, altitude and anomalies experienced. An example of flight logs used by ERL is contained in Reference 2. These include the thermal scanner log, magnetic tape calibration log, photographic log and aircraft log.

6. Voice Annotation

Voice annotation of the magnetic tape is important for two reasons:

a. Recording pertinent information necessary to interpret tape recorder calibration data.

b. Placing flight parametric data onto tape to assist subsequent data tape handling and data processing.

Voice annotation is usually placed on one tape track and records all voice communication via the sensor crew intercom and the air-to-ground radio links. Because the voice annotation is activated while data is being taken, the information on this tape track complements and augments the data on the airborne operator's logs.

7. Surface Measurements

Advances in the state-of-the-art of thermal remote measurement from aircraft have reduced surface measurements for calibration purposes to a minimum. For small geographic areas where atmospheric conditions are uniform only one boat is required. Reference 2 gives the procedure for taking surface temperature measurements from a boat. In addition to the water temperature measurements, some meteorological data such as wind speed and direction, air temperature, humidity and cloud cover distribution and altitude are sometimes required or at least helpful for atmospheric corrections.

Other than the usual logistic problems with boats the only consideration relative to remote thermal measurement calibration is that of coordination with the aircraft. To assure the maximum validity of the surface measurement it should be acquired at a location that can be easily identified in the remote data and it should be acquired at the same time that the aircraft is at the same location. Alternately, a series of measurements around the time of aircraft flyover would allow the construction of the time history of surface temperature at the desired location. Very often the circulation characteristics in a target area are dynamic enough to require a measurement at the time of flyover. However, in all cases where a boat is used it is necessary to identify the location and time of the surface measurement in the remote data because of the methods used for making atmospheric corrections.

8. Post Acquisition Activities

After completion of flight and surface measurement activities the photographic film, magnetic tapes, flight logs and surface measurement logs are returned for data processing, cataloguing and indexing. Photographic film is submitted immediately to a photo lab for processing and production of a positive transparency product. Magnetic tapes and flight logs are returned to a quick-look processing facility. Surface measurement logs are retained for later use in the data processing procedure.

At the present time at ERL the procedures for determining overall thermal scanner measurement accuracy are being developed. (See Section V) If the final procedure dictates a post-flight calibration procedure this activity should take place immediately after landing as part of the post acquisition procedure.

IV. DATA PROCESSING

Data processing includes all functions performed on the analog data tapes and 70mm film from the time those items are removed from the aircraft and brought to the data center or laboratory until the final product is ready to be prepared. The following data processing discussions and procedures will be divided into three parts: Quick-Look Data Verification, Qualitative Analog Data Product, and Quantitative Digital Data Product.

A. Quick-Look Data Verification

This activity allows the user to evaluate the validity of the data acquired in a short time frame after the survey is conducted. Many times problems can be discovered early before much effort is expended in processing the data.

The data tapes as recorded during the flight are the basis for all thermal information acquired. Precaution should be used and standard procedures followed when handling and processing the tape. A duplicate should be run and the processing done from the duplicate with the original stored in a safe place.

The following basic steps are required for quick-look data processing.

1. An oscillograph recorder provides a hard copy record of the data acquired on the analog tape. The O'graph record is used to get a quick-look at the calibration, sync and video signals, to assess system operation and verify calibration and data acquisition times during the survey. An alternate method of quick-look processing involves the use of an oscilloscope. However, this method is more time consuming and there is no hard copy record of the data produced except that photographs may be taken of the scope to document specific problem areas on the tape.

2. The ground based RFR-70 film recorder used with the RS-18 thermal scanner converts the analog signal (light energy) to a 70mm photographic film via a cathode ray tube (CRT) trace, which is focused by a lens and mirror onto the film that is moving across the face of the CRT tube. This film must then be developed and copies run by standard processes. The film image is a black and white representation of surface temperatures where the different shades of gray represent different surface temperatures. Usually a film positive is produced where the lighter the shade of grey, the warmer the surface temperature. The light table is used for review of this imagery. At this time in the procedure all of the magnetic tape data is processed through the film recorder. Only a small time slice is photographically processed into a black and white transparency for data quality verification.

3. Simultaneously with the review of thermal scanner data on the oscillograph and the tape to film conversion, the aerial photography obtained from the camera boresighted with the scanner is processed. It is reviewed during the quick-look process to aid in determining whether the aircraft generally followed the planned flight lines and

whether landmarks, boats, buoys are locatable and identifiable for subsequent determination of actual flight lines.

4. Utilizing data acquired from the quick-look data verification processing a Quick-Look Report is prepared for the user to determine the overall quality of the data. Inputs are made from the oscillograph, oscilloscope, analog imagery and aerial photography. Reference 2 gives an example of a Quick-Look Report which consists of the following information:

a. Mission summary
b. Flight and surface measurement requirements
c. Aircraft flight plan
d. Operator's Logs
e. Magnetic tape quick-look report
f. Photographic quick-look report and flight map
g. Anomalies experienced.

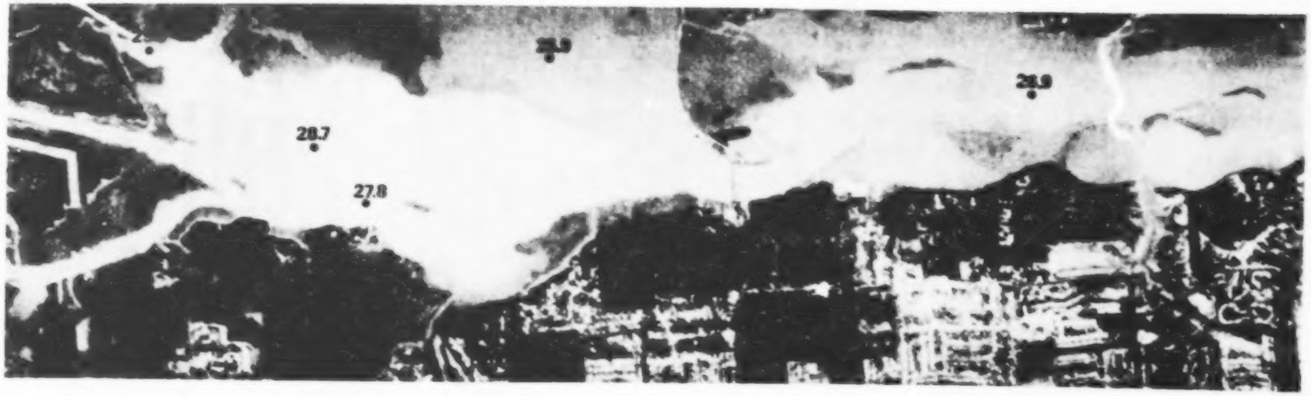
In summary, the verification of the airborne data is accomplished by review of an oscillograph record made from the analog data tape, a small portion of thermal imagery processed from film obtained from the tape using tape to film conversion equipment and the aerial photography obtained with the boresighted camera.

B. Qualitative Analog Data Product

Assuming that the quick-look activity has verified the general quality of the data, an interim product may be prepared which is suitable for preliminary analysis of water surface thermal conditions. This imagery is qualitative in nature since absolute temperature is not presented. Relative surface temperatures may be inferred from the variations in grey tone. The value of this product may be enhanced by the notation on the imagery at appropriate locations of any surface measurements made during the survey or mission. Supporting data consists of actual flight lines plotted on a reference map and derived from the photographic and/or thermal imagery.

The data product consists of a strip(s) of black and white imagery which represents surface temperature in shades of grey covering a swath of area to either side of the flight line, and an actual flight line map derived with the aid of aerial imagery. An example of the product is shown in Figure 4. It is produced from the data magnetic tape by using a film recorder as described previously. It may be produced as a positive (lighter grey tones represent warmer temperatures) or as a negative (lighter grey tones represent cooler temperatures) product depending on use or preference. For example, clouds below the aircraft appear white in a negative and black in a positive product. The product may also be produced as paper print or as a transparency for use on a light table. Depending on use, the transparency or print may then be annotated with the surface measurement temperatures taken at the same time as the remote measurements. Location of the surface measurement points in the analog product is accomplished using the geographic features on the analog image itself aided by the boresighted aerial photography. Relative surface temperature distribution can then be inferred from the grey tone distribution. One problem with this product is that it is difficult to match grey tones in areas of imagery overlap on parallel flight

STOP 09:44:15 CDT



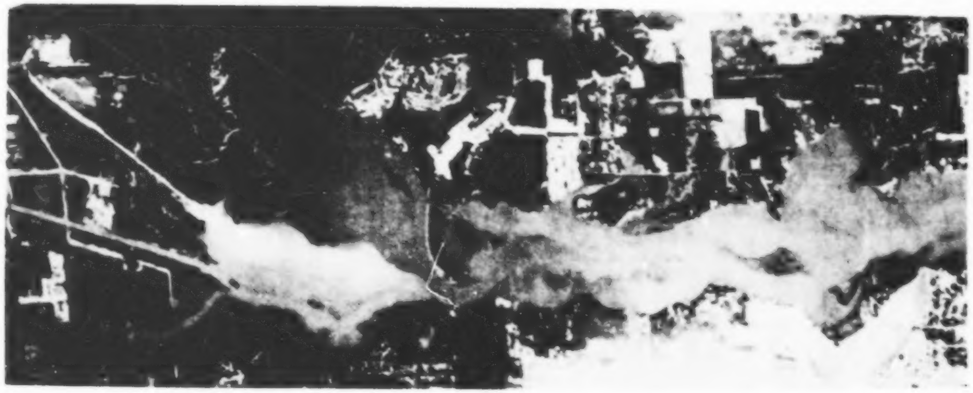
START 09:42:40 CDT

ALTITUDE 3000 FEET
19 SEPTEMBER 1973

ORIGINAL FORMAT FROM
TAPE TO FILM CONVERTER

APPROXIMATE SCALE 1:32,000

STOP 10:14:32 CDT



START 10:11:43 CDT

ALTITUDE 6000 FEET
19 SEPTEMBER 1973

ORIGINAL FORMAT FROM
TAPE TO FILM CONVERTER

APPROXIMATE SCALE 1:74,000

[illegible].5 SURFACE TEMPERATURES °C
● BOAT STATION

LIGHTER TONES INDICATE
WARMER TEMPERATURES

BILOXI BAY

INDEX MAP

QUALITATIVE ANALOG DATA PRODUCT

Figure 4

lines during photographic processing and, therefore, it is difficult to mosaic imagery from parallel flight lines. However, this has not proven to be a serious constraint in the use of the data.

One particular advantage of this product is that it may be produced almost immediately after acquisition, assuming the close availability of a photo lab. At this time the user should review the entire set of data including the aerial photography. The purpose of the review is to verify that the quality of the thermal product meets user requirements and to select the data to be further processed to produce the quantitative digital data product. Detailed procedures for producing the analog product are given in Reference 2.

C. Quantitative Digital Data Product

The quantitative digital data product obtained from the thermal scanner is produced through computer processing from the analog magnetic tape and is shown in Figure 5. The product may be left in digital format on tape for entry into a data bank or may be produced as a grey scale image where each grey level corresponds to a selected temperature interval. In addition, numerical temperatures may be superimposed on the grey scale image giving absolute temperature on a selected uniform pattern. This product is prepared according to requirements specified by the user after review of the analog product. The following discussion describes the techniques and procedures used in producing the digital product.

Data from the RS-18 thermal scanner is recorded on one track of an Ampex AR-700 Analog Magnetic Tape Recorder along with housekeeping and calibration data. Scan line synchronization data from the RS-18 is recorded on a second track of the recorder. A data bandwidth of 50KHz requires that the recorder, utilizing wide band Group II electronics, be run at 15 inches per second or higher.

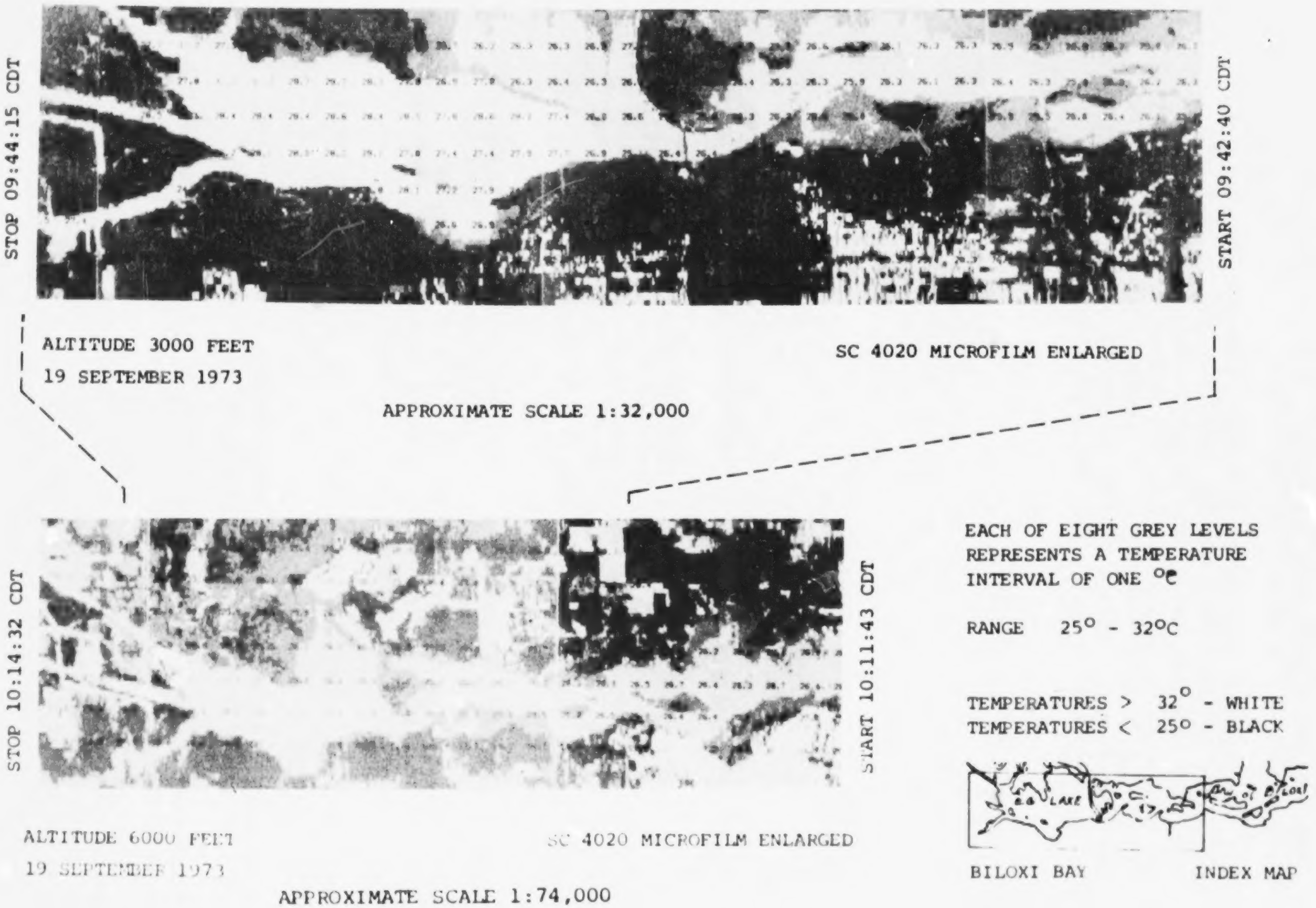
Recording the scanner data in an analog format requires that an analog to digital (A/D) conversion be accomplished to synchronize the appropriate pulses and time reference the calibration and video data for subsequent computer processing. Certain parameters are required as inputs in order to perform the analog to digital conversion. These include:

1. The inflight tape calibration log for verifying calibration voltage levels on the tape.

2. The Oscillograph quick-look record for verification of calibration voltages and data time interval, and an indication of data quality.

3. The Quick-Look Report to determine whether anomalies exist on the tapes and if so what correction factors could be applied.

Once these parameters are identified and the appropriate inputs made from this data the analog to digital process is ready to proceed. The A/D conversion is accomplished on the SDS930 computer at the Slidell Computer Complex (SCC). A description of the A/D software program is contained in Reference 2.



QUANTITATIVE DIGITAL DATA PRODUCT

Figure 5

The output of program AP174 are digital data tapes containing counts representative of the raw analog detector voltages and time. These digital data tapes and the documents described below are required for the next processing step.

1. Inflight tape calibration log for determining calibration voltage levels.

2. RS-18 thermal scanner inflight log for sensor configuration and time correlation.

3. Actual flight line map for determining approximate grid orientation.

4. Aircraft flight log for determining heading, estimated ground speed, anomalies, altitude, cloud cover and haze conditions.

5. Photographic equipment log for verifying flight time to refine grid orientation.

6. Analog film for determining locations and relative values of surface temperature and to determine areas of isothermal water for atmospheric correction techniques.

7. Analog to digital conversion report to provide tape number, time slices, and data quality.

8. Surface measurements data to verify temperature values and meteorological conditions.

The Univac 1108 computer and associated "off line" devices are used in the next stage of data processing. The sensor data was previously processed through A/D conversion routines and recorded on digital magnetic tape. The digital tapes are stored in the computer area tape library and respond to data processing commands. A digital program tape is also stored in the tape library and responds to data processing commands. The program contained on this tape is described in Reference 2. This program, using the digital data tape containing raw data counts, averages the appropriate number of scan lines, applies the blackbody calibration curves and also applies the selected atmospheric correction.

The specific order of data processing is contained in the following steps:

1. The data user defines the new type of final product desired. The definition of the final product includes the number of copies, format, content, etc. A typical data product is defined as follows:

    a. Produce digital data product of the survey area formatted as follows:

        1) Shades of grey scale to change in .5°C increments over water.

2) Imagery to be overlayed with numerical temperatures at standard intervals (seven values across picture)

3) Apply the best possible atmospheric correction to the data.

2. A sample portion of the data is processed to determine overall quality.

3. After the necessary data quality runs are made a determination of the best method to apply atmospheric and instrument corrections are made. Several options are available to the processor as follows (refer to References 2, 3, 4 and 6 for additional details on these options):

a. If an area of isothermal water is available the computer can be instructed to determine a corrective factor by inputting time and surface temperature. This technique corrects for both atmospheric conditions and instrument error.

b. Atmospheric corrections based upon the RS-18 scan mechanics can be inputted to the computer. This can be used both with or without a known surface temperature. Instrument error can also be removed by this technique.

c. Corrections based on radiosonde sounding can be applied to the data which does not correct for instrument error. This technique is still under development and is not recommended as a standard procedure. However, the option of using it is available in the software.

d. Data can also be corrected by an arbitrary mathematical method which would be used as a last resort and is also described in Reference 2.

4. After testing the data and determining a method of applying atmospheric and/or instrument correction all the data is processed to obtain data tapes containing time and absolute temperature in counts.

Digital derived imagery overlayed with numerical temperature is produced by processing the tape obtained in Step 4 above, through the Univac 1108 computer and an "off line" S-C 4020 plotter. The program used with the plotter is described in Reference 2 and converts the corrected counts into temperature units which are then used to produce the selected gray level intervals and numberical overlay in the correct orientation. The output from this process is 35mm film imagery and a supplementary paper output which records the processing parameters used to achieve this film output. The film can then be processed into paper products as shown in Figure 5. In addition, the digital computer tape with suitable formatting may be used for direct entry into a digital data bank. It should be noted that in the quantitative digital product only the temperature values over water are valid since the emission properties of the land are so variable and not well known.

V. QUANTITATIVE DIGITAL DATA PRODUCT ACCURACY

The following discussions described approaches being considered at ERL to define the digital product accuracy. Primary error sources are considered to be system errors including instrument and processing errors, atmospheric correction technique errors and geometric errors. In addition, other sources of error not as significant as the above are also being investigated. The results of these investigations will be reported as completed. The present level of experience with the system indicates that an absolute remote measurement accuracy of ±0.5°C from a light aircraft is a reasonable goal.

A. System Errors

The accuracy of a temperature determination employing thermal scanner generated data is a function of the various processes involved in data acquisition and subsequent data processing. What is of primary importance is the total end-to-end system/data reduction accuracy. An approach to determining the accuracy consists of placing an extended area blackbody source (with a temperature accuracy of ±.125°C) four feet beneath the scan head and recording the video and sync wave forms on the actual data acquisition system employed on the data collection aircraft. Data will be recorded at three blackbody temperatures: a temperature near the set temperature of scanner blackbody number one, a temperature midway between blackbody temperatures numbers one and two, and a temperature near that of blackbody number two. This data will then undergo the standard thermal scanner data reduction routine, consisting of A to D processing and subsequent temperature profile printout through Univac 1108 processing. A comparison of the derived temperature with the true blackbody source temperature yields the overall end-to-end system accuracy. No atmospheric attenuation correction is necessary in this case due to the extremely short (four feet or less) path length.

Once the system accuracy is determined an assessment can then be made of those processes within the system that can be considered the major sources of error and candidates for further development effort selected.

The scanner by itself has a possible 0.87°C R.S.S. error in temperature determination. This stems from two separate error sources. The first is in the measurement made of the temperature of the scanner internal blackbodies. A platinum resistance thermometer is imbedded in the center of each of the blackbody sources. Each sensor is connected to a linearizing bridge which feeds electronics for gating blackbody temperature information into the video signal. The bridge outputs are accurate to better than 0.5°C, typically 0.25°C. Neglecting further electronically induced error maximum error of 0.5°C exists in blackbody temperature measurements.

The second source of error stems from the non-linear nature of blackbody radiation. In the data reduction process the video signal is compared to the signal levels produced by the two blackbodies and the corresponding video temperature is determined by assuming a linear relationship between voltage out versus temperature. However, blackbody radiometric input energy is not linear with temperature thus voltage out must also be nonlinear. Calculation has shown that if the blackbodies are operated with 15°C temperature (typical at ERL) and the video level falls midway between radiometric BB #1 and BB #2, a .5°C error is introduced.

B. Geometric Errors

Positional errors or those errors that result from platform location are difficult to define in some cases since they are a function of two different recording scales - across flight and along flight. Scales in direction across track are relatively constant. Scales in directions parallel to the flight track may vary from the cross track scale in one imagery strip due to velocity to height ratio of the aircraft. Ideally, these scales are matched during processing, which requires exact application of ground speeds. The scanner data is usually processed with the ground speed as estimated during flight with no special corrections applied; therefore, the scale of the infrared imagery may vary in the direction of flight.

C. Atmospheric Correction and Other Errors

A significant amount of thermal scanner data has been digitally processed at ERL using the several different methods of atmospheric correction described previously. An analysis of this data using comparison of the several techniques and comparisons of remote and surface measurements is underway to determine an accuracy estimate for each technique. In addition, other sources of error such as accuracy of in situ instruments and sea-air interface effects are also being investigated to determine their contribution to the overall remote temperature measurement technique error.

VI. PERSONNEL, SCHEDULE AND COST

A. Personnel

Staffing required for conducting a surface water temperature survey depends upon the frequency of usage and turnaround time required for products. However, assuming 3½ flight line hours per week or about 175 flight line hours per year of mission performance with no extremely tight schedule demands for products, the following types and numbers of personnel should be able to perform the task with reasonable effectiveness.

Type	No.
Electro-optical Engineer	1
Electronics Technician	½
System computer programmer*	½
Computer production specialist	1

*Required for one year only or until software package is operational.

The elctro-optical engineer may be one with formal training in electronics and experience in or association with the field of optics or the reverse would be acceptable where the person had received formal training in physics with experience in or association with electronics. Duties of the engineer would include overall responsibility of the system, provide engineering procedures for installation, checkout, modification, and calibration of the system, fly with the system to assure proper operation, assist the user in analyzing and interpreting the quick-look and final products.

An electronics technician with experience in solid state circuitry could perform calibration and maintenance on the system by devoting one half (½) work time to the system. In addition to calibration and maintenance the technician could assist the electro-optical engineer and others with duties as required.

The systems computer programmer's job consists of modification of existing software for adaptation to the particular computer system the user has available for data processing. This effort may require more than one half time for the first year but after the software package is modified, checked out and in operation, the effort required for maintenance and modification of the software would be practically zero. Familiarity with the sensor and other components of the thermal scanner is required of the systems programmer.

Duties of the computer production specialist include coordination of processing with the computer group performing the analog and digital data reduction, displaying the data utilizing the program options and lead card setup required by the user and coordination of all operational processing efforts.

In summary, the equivalent of three people initially or 2½ after the software package is operational can effectively perform a temperature survey. It should be recognized that personnel required for other functions such as aircraft operation, photo and computer processing are not included.

B. Schedule

The Temperature Survey Schedule and Flow Diagram, Figure 2, shows that under normal conditions a typical survey can be performed in about 15 work days. Quick-look verification data can be produced in most cases in 1 day or less and a qualitative product in about 3 days. Total work days required can be reduced substantially with all supporting groups such as photo and computer processing working on a high priority basis.

C. Cost

The basis for estimating the user cost of the data for a survey is the flight line nautical mile. A flight line mile of data is acquired when the overflight aircraft or data platform traverses one (1) nautical mile of a prescribed flight course with the sensor system in the acquisition mode.

Computer processing costs for this report have been determined based on experience gained at the JSC/Earth Resources Laboratory at MTF with the following rates for labor and computer CPU time:

1. Labor - $10 per hour
2. SDS930 - $97 per hour
3. Univac 1108 - $287 per hour

In addition, the CPU time to flight line time ratio was established at three to one for RS-18 thermal scanner data processing on the Univac 1108 computer and four to one on the SDS930 for a speed of 150mph and an altitude of 10,000 ft. (Lower altitudes would increase cost somewhat because of the increased number of scan lines to be processed.) Using the above rates the costs for SDS930 processing is $2.60 per mile and Univac 1108 processing is $5.74 per mile. Also the manhours associated with processing a 30 min. or 75 mile mission for the SDS930 and Univac 1108 are 20 and 30 manhours, respectively. This is illustrated in the following chart.

RS-18 Thermal Scanner Data Processing Costs ($) per Flight Line Mile
(Nautical)

Computer		Labor	Total	Product
SDS930	Univac 1108			
$2.60	$5.74	$6.70	$15.04	1) Grey Level Scales w/grid
			2,00	2) Imagery (analog film)
			0.50	3) Film positive photo (color)

At an altitude of 10,000 ft. the ground scan width is four nautical miles. Therefore, the data processing cost would be $4.28 per square nautical mile.

To obtain total cost of the survey per square nautical mile would require the addition of such costs as salaries, equipment and rentals for the other survey phases like calibration, maintenance and surface/flight data acquisition. Costs associated with many of these other aspects are discussed in Ref. 7.

VII. CONCLUDING COMMENTS

Techniques and procedures for quantitative surface water temperature surveys described in this document have been developed using the Texas Instrument RS-18 thermal scanner. It should be noted that other scanners are available on the market, and that these procedures with minor modifications should be applicable for use with these sensors. A similar comment is also applicable to the major processing equipments involved i.e., the UNIVAC 1108 and the SDS930 computers. In addition, the procedures are applicable to higher altitude aircraft and satellite acquired data provided the proper modifications are made to the atmospheric correction procedures.

As more experience is gained in the use of the scanner equipment, processing techniques and in the applications of the products, further refinements will be made in the procedures to reduce cost and improve schedule. Some of these refinements that are in work include: 1) Software simplification to minimize computer capacity and processing requirements; 2) The development of alternate display formats utilizing simpler procedures; 3) Providing a system end-to-end accuracy/calibration procedure to be performed as a routine survey activity.

In conclusion, a procedure is presented for the conduct of water temperature surveys utilizing a commercially available thermal scanner, leased light aircraft and data processing equipments and provides qualitative and quantitative display products as well as digital computer tapes for entry into a data bank.

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REMOTE SENSOR IMAGERY ANALYSIS FOR ENVIRONMENTAL IMPACT ASSESSMENT

by

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ABSTRACT

A conceptual framework is presented for the application of remote sensing to problems confronted by the Environmental Protection Agency. Essentially the framework provides for the derivation of basic information necessary for an understanding of complex environmental relationships, followed by the application of this information to problems of immediate and long-range concern. Both basic and applied information is generated by an interactive interdisciplinary team utilizing remote sensing as the focal point of its study. EPA problem areas in which remote sensor imagery analysis can assist include location and characterization of pollution sources, assessment of impact, projection of trends and potential problem areas, determination of appropriate control and preventative measures, and acquisition of necessary base line and periodic data.

INTRODUCTION

The problems of concern to the Environmental Protection Agency are highly complex, and for their solution often require an understanding of numerous interacting facets of the environment. The study of these problems--how they arose, how they can be solved, how they can be prevented--lies in the province of environmental analysis. Among the greatest potential aids to such study are the tools and methods of remote sensing. Furthermore, an adequate unravelling of environmental complexities is best accomplished through interactive study by a diverse team of investigators, each of whom is highly qualified in a different physical, biological, cultural/social, or engineering discipline. It follows, then, that a most effective approach to environmental analysis is via the study of remote sensor imagery by such an interdisciplinary team.

It seems appropriate in a meeting such as this, in which new sensors and techniques are being discussed, to include a reminder that existing remote sensing technology and methods are available to address many of the problems with which the EPA is confronted. The purpose of this paper is to present a conceptual framework for the application of remote sensing to these problems. This framework provides fundamentally for the derivation of basic information essential to the understanding of environmental interactions and probable reactions to various stresses. This key function was mentioned earlier, and we shall refer to it here as the "interdisciplinary environmental analysis." The broad data base thus produced has application both to immediate problems and to long range study and planning. In both the basic and applied phases, the framework can utilize both the old and the new. Conventional, off-the-shelf imagery and methodology are useful, as well as new sensors and techniques; well-established knowledge can be exploited, in addition to current research into the complexities of the causes and effects of environmental stresses. In any case, however, we feel that the emphasis in the environmental analysis should be more on the ordering and exploitation of the intellectual processes of the group members, both individually and as a team, than on remote sensing hardware or systems.

The benefits accruing from interdisciplinary input to environmental problems are widely acknowledged. The research program of EPA itself is strongly interdisciplinary in nature. The approach described here is not a departure from this concept, but rather a tool, a format, a focal point for amplifying the effectiveness of an interdisciplinary team. Remote sensor imagery is virtually unequalled in its capability for giving a unified representation of an environment, free from the arbitrary compartmentation we tend to impose upon it. If we add to this a carefully chosen, skilled team, functioning in a truly interactive, synergistic mode, and utilizing a proven framework for ordering their thought processes, a great deal of reliable information can be generated quickly and economically. Of prime importance here is the realization that imagery gives us nothing: we must extract information from the imagery as a function of our knowledge and core of experience.

As indicated earlier, this paper presents a conceptual framework. One reason for considering it so is that, while the cornerstone--the interdisciplinary environmental analysis--has been tested and proven repeatedly, many of the specific applications to EPA problems are less well grounded. To date, our own experience in these applications has been limited. We have been involved, however, in a wide variety of other imagery analysis applications, including several associated with natural and man-induced environmental stresses. Based on this experience, we believe this approach to be basically sound, and look forward to its being tested on EPA problems.

The interdisciplinary environmental analysis procedure will be summarized, followed by a brief presentation of some of the ways we believe remote sensing can be used to address problems of concern to EPA.

THE ENVIRONMENTAL ANALYSIS

Most remote sensing imagery interpretation procedures can be assigned to one of two broad categories. These categories are perhaps better thought of as extremes of a continuum, for a line that precisely separates the two is difficult to distinguish. At one end are those techniques associated with direct detection and identification of discrete objects. At the other end are the methods that are best described as analytical or interpretive in that they rely on inductive and deductive evaluation of the various environmental components in terms of the knowledge, field experience and academic backgrounds of the individuals concerned. These require a team effort in the true sense of the word.

In the context of EPA's problems, if the sole objective of a study is the detection and/or monitoring of some forms of pollution, and if the technology for the task is well developed, it would be a waste of energy and time to go through the laborious analytical procedure. On the other hand, if the study is more complex, involving such matters as assessment of short- and long-term impact of certain stresses, projection of trends, and recommendations for corrective or preventive measures, then the detection-oriented task will be inadequate.

The interpretive procedure, or environmental analysis, relies on associating numerous threads of converging evidence. It considers any and all information that can be obtained: all pertinent forms of remote sensing data, ground photography, field notes, maps, texts, reports, current research findings, as well as the education and experience of the individuals involved. It is well to remember that the imagery is not so much the source of information as it is the focal point of attention for the knowledge, experience, and judgment possessed by the team members. It is a well worn but true example that a person cannot extract much meaningful geological information from a photo if he knows nothing about geology.

Man tends to divide the landscape or environmental elements into neat packages--e.g., polar regions, tropics, etc.--which, like his educational units, are useful but nevertheless somewhat arbitrary and often artificial. In fact, of course, there is a transition from the polar regions to the tropical areas--it is not a step function--and there is an equivalent transition in the elements of pattern of the landscape as well as in the adaptive patterns of man and other biological systems to these climatic landform complexes. Within any area, the delineation, texture, chromaticity and configuration of the landscape elements form a characteristic arrangement that is unique to that place at that time. Various physical, biological, and cultural forces have interacted with each landscape element in a given manner and in a given sequence. The complexity of detail within this image represents the scene at one brief instant in the continual interplay between the forces of nature and the materials of nature. To the extent that these relations and complexities are understood, a team not only can determine the present, but also can deduce much of the past and predict future trends in response to a given stress. Hence the rationale for our procedure of imagery interpretation.

The diagram in Figure 1 is an organizational chart that shows the relationships of the various phases of the analysis. Again, this is a conceptual outline rather than a rigid operational one. People will find their own ways of working at a given task and, during an actual analysis, it might be difficult to identify each of these steps except for the beginning and the end. It is beyond the scope of this paper to give a detailed description of the entire procedure. A few comments may be appropriate, however.

The type of imagery selected for the study, of course, depends on its purpose. In many cases, however, we find that the "horse blanket approach"--i.e., using standard off-the-shelf panchromatic aerial photography--provides most of the information required in the basic environmental analysis. Much of the needed photography is already in existence in federal, state, or commercial files, and may be purchased for a nominal sum. A case in which existing aerial photography was used to conduct an interdisciplinary environmental analysis on a large scale quickly and economically was the involvement of our Division in Project Sanguine. The purpose of our contribution to Sanguine was to provide the Navy with environmental information about northern Wisconsin and bordering Upper Michigan useful for developing engineering plans, cost estimates, and projections of environmental impact for an envisioned communications system. Several terrain components--landforms and soils, surface drainage, bogs and other organic wetlands, and land use and cultural involvement--were assessed and mapped over an area of 22,000 square miles in a time period of fourteen months--late 1968 through early 1970. Total cost was $250,000, or less than $12 per square mile.

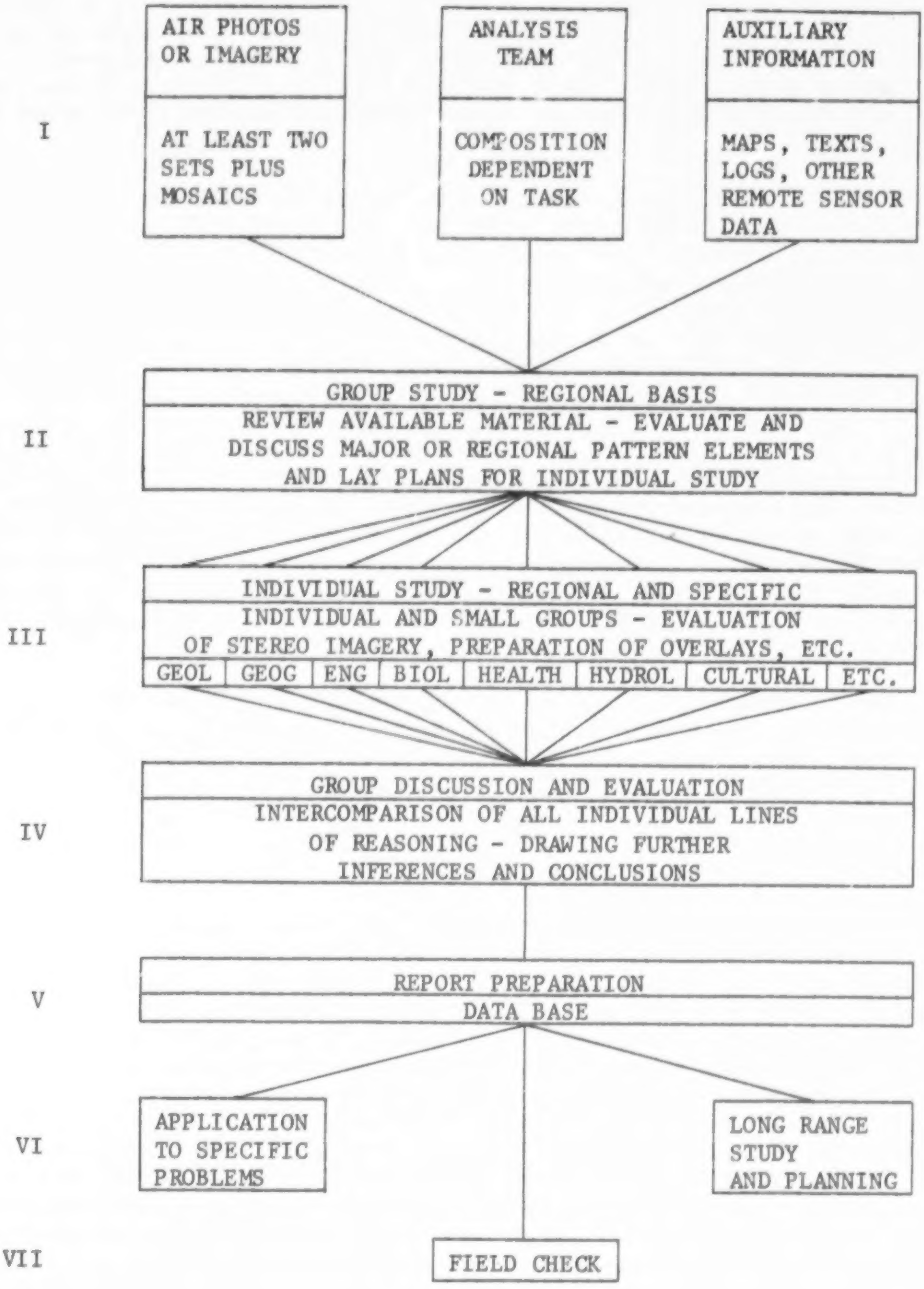
AIR PHOTOS OR IMAGERY
AT LEAST TWO SETS PLUS MOSAICS
ANALYSIS TEAM
COMPOSITION DEPENDENT ON TASK
AUXILIARY INFORMATION
MAPS, TEXTS, LOGS, OTHER REMOTE SENSOR DATA
I
GROUP STUDY - REGIONAL BASIS
REVIEW AVAILABLE MATERIAL - EVALUATE AND DISCUSS MAJOR OR REGIONAL PATTERN ELEMENTS AND LAY PLANS FOR INDIVIDUAL STUDY
II
INDIVIDUAL STUDY - REGIONAL AND SPECIFIC
INDIVIDUAL AND SMALL GROUPS - EVALUATION OF STEREO IMAGERY, PREPARATION OF OVERLAYS, ETC.
GEOL
GEOG
ENG
BIOL
HEALTH
HYDROL
CULTURAL
ETC.
III
GROUP DISCUSSION AND EVALUATION
INTERCOMPARISON OF ALL INDIVIDUAL LINES OF REASONING - DRAWING FURTHER INFERENCES AND CONCLUSIONS
IV
REPORT PREPARATION
DATA BASE
V
APPLICATION TO SPECIFIC PROBLEMS
LONG RANGE STUDY AND PLANNING
VI
FIELD CHECK
VII

Figure 1. A simplified presentation of the major steps in an environmental analysis.

The use of existing photography to provide not only synoptic coverage, as in Project Sanguine, but also sequential coverage of an area can be particularly important for EPA studies seeking to establish patterns and trends of population growth, industrial expansion, and agricultural practices, to name a few. To the extent that additional imagery types are required, such a primary analysis serves as an excellent focal point for planning for the most expeditious acquisition and use of these other types. We feel this is preferable to the procedure of initial "saturation bombing" of the area with many sensors, which not only is expensive, but also can set one up for a painful case of data indigestion. This certainly is not said to detract from the capabilities of the more sophisticated sensors, but simply to urge their wise and discriminate use.

Regardless of the imagery type used, the study should start with an analysis of the smallest scale available. ERTS images often serve this function very well. Photo index sheets--usually larger in scale than ERTS images--are also useful for this step. Next, individual photographs, perhaps at a scale of 1:15,000 to 1:20,000, are laid out to form a large mosaic of the area. On this, one can delineate gross pattern features and note their interrelationships as well as their mutual influence on particular areas of interest. Then comes a detailed study of each set of stereo pairs. Pattern elements are visible on the very small scale imagery that are not apparent at the larger scales, and the reverse is also true.

Since the purpose of an environmental analysis is to obtain as much information as possible about any given environment by interpretation of remote sensor data, it follows that a team composed of members with different professional experience in the fields of science and engineering will accomplish more than a group whose backgrounds, training, and viewpoints are all similar. How many people and which backgrounds should be represented are a function of the assigned task and of the resources and people available. Our contribution to Project Sanguine, for example, utilized twenty professional people, working in four interdisciplinary teams, and representing the disciplines of geology, geophysics, hydrology, soils, mathematics, physical science, botany, forestry, agronomy, ecology, economics, geography, and civil engineering. For many studies a team of five to eight is enough to provide sufficient breadth of background knowledge and yet small enough to be manageable as a single group. The team probably should include one or more members with expertise in the specific application areas to be addressed after the basic environmental analysis is completed. For some pollution studies, an industrial chemist, a fishery biologist, or an environmental laywer might be considered. It should be pointed out again that the emphasis in the analysis should be on the people--their backgrounds, training, interest, ability to function effectively in a group, and capacity for creative thinking--rather than on hardware.

Appropriate auxiliary data should be exploited to the full extent permitted by the time and resources available. Remote sensing is not an end in itself, but a very useful tool to be utilized in concert with other tools in seeking an improved understanding of the environment and a solution to specific problems. In the case of EPA's problems, we are dealing with a host of complex interactions, many of which are poorly understood. It is obvious that remote sensing will not give us all the answers. Accordingly, past and present research work should be employed freely. The remote sensing team analysis can comprise a highly effective focal point for evaluating, integrating, extrapolating, and applying these research findings in the context of the specific environment and problems being addressed.

The group discussions indicated in Parts II and IV of Figure 1 are important and provision must be made for these sessions. A group of five people working separately (each in his own room working on photos and writing his section on geology, cultural patterns, etc.) is not equivalent to five people around a table with photography and stereoscopes, arguing and debating each point as it develops. By the same token, time must be allowed for individual thought and pondering.

The analysis is strongly interactive; it thrives on feedback. A point which surfaces in group discussion may provide the stimulus for in-depth study by one of the other team members. The reverse is also true. Similarly, as the analysis progresses, it may become evident that certain types of auxiliary information, perhaps including other remote sensing data, are now needed. A field check of the interpretation, whenever this is possible, provides invaluable feedback, both by improving the quality of the current work and by adding to the fund of experience of the team members, thereby permitting them to do a better job the next time.

Figure 2 shows an outline which has proven useful as a general guide for considering terrain elements in an environmental analysis. It provides for a regional and local analysis, an interrelating of the various components of the analysis, and application of the results to specific problems. Modification and amplification of certain parts of the outline undoubtedly will be required in response to the different objectives of different studies. Whether this or another outline, or none at all, is used, the important thing is that all significant environmental parameters be considered rather than just isolated pieces of the environment. Naturally, the degree of detail in which various aspects are treated will be tailored to the objectives of the study. However, giving some attention to all aspects helps to insure that potentially important factors and interactions will not be ignored, and provides the framework into which more detailed data, if required later, can logically and efficiently be fitted.

Having at our disposal the information derived from the environmental analysis, we now can begin to address the more specific objectives of the study. This may include any of a broad array of problem areas--basic ecological studies, resource management, planning for rational development, site selection for construction activities, military planning, or assessment of environmental impact, to name a few. The preparation of environmental impact statements is a major concern of several agencies, including the U. S. Army Corps of Engineers, of which our own organization, the Engineer Topographic Laboratories, is a part. The pollution-related problems for which EPA has primary responsbility, and which we will now consider more specifically, may be considered a very large subset of environmental impact problems. To all these problems, we believe, the environmental analysis approach summarized here has much to contribute.

APPLICATIONS TO EPA PROBLEMS

The application categories which follow are presented in a more-or-less chronological order. The categories, as well as the chronology, are sometimes ill-defined and overlapping. They are used here primarily to lend some degree of order to the discussion. Strong interactions and feedback among all these categories can be anticipated.

As with the basic phase of the analysis, full use should be made of past and current research. Furthermore, opportunities should be exploited for the

OUTLINE GUIDE FOR ANALYSIS OF NATURAL FEATURES USING AIRPHOTOS

I. Regional Aspects (Major Environment) - study of photo mosaic

- A. Geography of Region
  1. Location - physical aspects, space relationships, civil and political.
  2. Economic Aspects - Land use and major apparent economic interest.
  3. Transporation Aspects - All Types
- B. Physiography of Region
  1. Mountains
  2. Hills
  3. Plains
  4. Escarpments
  5. Basins

  In each, describe the physical expression in terms of form, character, extent, boundaries, degree of dissection. Look for indicators of these. Describe fully.
- C. Geology of Region - Origin
  1. Transported origin
     - a. Wind
     - b. Water
     - c. Ice
     - d. Gravity

     In each, look for the indicators of origin, movement, agent of movement and deposition - The mechanisms responsible. Describe fully.
  2. Residual origin
     - a. Igneous
     - b. Sedimentary
     - c. Metamorphic
     - d. Combinations

     Look for indicators of origin of those deposits formed in place. Describe fully.
- D. Climate of Region
  1. Arid
  2. Semi-Arid
  3. Sub-Humid
  4. Humid
  5. Tropic
  6. Polar

  Look for the indicators of climate in erosion, vegetation and land use. Pay careful attention to: Location and distribution of vegetation; intensity of erosion and redeposition; and presence or absence of irrigation.

II. Local Aspects (Minor Features Pattern or Elements) - Stereo-study.

- A. Land Forms
  1. Description of physical characteristics
  2. Space relationships
  3. Arrangement

FIGURE 2

B. Drainage Patterns

  1. Non-pattern
  2. Pattern type and Plan

  Bound, mark and describe fully all portions of the drainage net in a watershed.

C. Erosional Aspects

  1. Wind related forms (blow-outs)
  2. Water related forms (gully characteristics)
  3. Ice related forms
  4. Gravity related forms
  5. Chemical and thermal
  6. Biological

  In each, look for indicators of mechanisms, and describe fully. Draw sketches, showing profiles, plan views and cross sections of any erosional forms.

D. Photo Tones

  1. Tone arrangement
  2. Pattern causes

  Describe the arrangement of tones in terms of shades, contrasts, design, etc.

E. Vegetation

  1. General classes

    a. Barren
    b. Grass
    c. Brush
    d. Timber

    Describe in terms of location, extent, density, slope, exposure, etc. If possible describe the structural character.

F. Special Features

  1. Unique/unusual features. Describe fully (unusual features) in terms of space relations, physical aspects, forms. Look for indicators of origin.

G. Cultural Aspects

  1. Man's activities

    a. Urban
    b. Rural

    Description of the type use and alteration of the landscape. Describe the intensity of man's activities.

III. Analysis - summations

A. Regional

  1. Summation
  2. Relationships
  3. Interdependencies

B. Local

  1. Summation
  2. Relationships
  3. Interdependencies

FIGURE 2 (Cont'd)

    - C. Local with respect to regional

- IV. Interpretation of data
    - A. Summary
    - B. Evaluation, Significance
    - C. Interpretation of data with respect to problems

FIGURE 2 (Cont'd)

analysis team to combine imagery analysis with field activities. These points are especially important in view of the meager state of knowledge about many pollution problems. For similar reasons, detailed procedures for most of the application portions of the analysis must await more practical experience in the use of this approach.

Source Location and Characterization

Our first task probably will be that of locating significant sources of pollution in a given area and characterizing them in terms of type and quantity of pollutants. Some sources already will be known. The location of others may become apparent after a rather cursory examination of aerial photography of the area--e.g., most significant stationary air polluters, feedlots and other concentrations of livestock, industries discharging substances which alter the color or turbidity of a water body, and refuse dumps. Next, work can begin on a listing and mapping of the location and nature of suspected or possible sources. In addressing this task, one could pose a wide variety of questions to which imagery analysis might contribute to the answers. For example, what have been the rate, pattern, and distribution of population growth in the area (the use of sequential imagery is implied)? What types of activities are the occupants engaged in--i.e., how do they use the land? How are the land use practices distributed spatially, and how have they changed with time? In what ways has industrial expansion occurred? What natural resources are available and how have they been exploited? What can resource exploitation, transportation systems, location, general appearance, and other indicators tell us about the nature of specific industries? What is the distribution of specific crops or natural vegetation types in relation to known uses of fertilizers and/or pesticides? Can we find anomalous features which might be pollution-related? In some areas "natural pollution"—e.g., saline springs or natural oil leaks--may cause significant problems, in which case geological and hydrological information derived from the environmental analysis could provide important clues to their localization. To the extent that sedimentation can be considered a pollution problem, the analysis can supply pertinent information about soil properties, topography, drainage characteristics, and natural and man-caused soil disturbances. Considerations such as these not only will help in determining likely trouble spots, but also should permit the elimination of many areas and pollution types from further consideration, at least for the present.

In this process, it may be possible to make a limited test of the validity of some of the data, inferences, and projections derived from our analysis by comparing them with locations and types of already known pollution sources. Hopefully, this will permit an improvement in subsequent analyses and inferences. To utilize such a test, of course, we would have to divorce ourselves initially from explicit information about these known sources.

At this point our predictions of source locations must be refined and pinpointed. Possible sources must be confirmed or rejected. Furthermore, we need rather precise data about the types and quantities of pollutants associated with confirmed sources. Obviously these requirements demand more detailed and specific sampling. The value of the foregoing step is that it suggests where to concentrate these sampling efforts, and to some degree, what sensors to use. Sampling efficiency is thereby greatly increased. Further substantial improvements in sampling efficiency may result from our ability to group, or stratify, areas which are relatively uniform with respect to likely locations and types of pollution. The relative ease with which terrain components can be stratified on imagery constitutes one of the most powerful assets of remote sensing.

A multi-stage sample strategy may well be indicated for many types of problems. The more generalized prediction stage can help provide a logical basis for the effective choice, flight planning, and utilization of other remote sensing data. Interpretation of the data acquired at this sampling stage should provide further refinements--rejection of some postulated sources, pinpointing and better characterization of others. For some purposes, acquisition of multiple scales of a particular type of imagery may be useful. For example, thermal imagery collected at a high altitude could enable the interpreter to make a general assessment of thermal pollution over a wide area, while lower flights could help to pinpoint, quantify, and determine fine thermal structure for particular trouble spots.

Much recent work has gone into the development of new remote sensing systems and the utilization of existing ones toward the end of pollution detection and characterization. These range from cameras equipped with special films and filters to airborne acoustical and ionizing radiation sensors. It is unnecessary to elaborate on the nature and capabilities of these here, particularly since many of them are being discussed in this meeting. Suffice it to say that they represent an impressive array of operational and potential tools with numerous applications to EPA's problems.

The refinements made at the second sampling stage increase sampling efficiency still more in terms of guiding locations for in situ sampling. Obviously, if the data are to be sufficiently definitive for legal purposes and for many scientific needs, sampling cannot stop short of the in situ measurements.

The entire process of location and identification of pollution sources will undoubtedly be iterative in nature. Data obtained on the ground may prompt a reevaluation of some portion of an earlier imagery analysis, and so on. Throughout, auxiliary data will be used heavily.

One of the products of this phase of the work should be a map, or, preferably, an airphoto mosaic, showing the precise location of each known source and a coded description of its pertinent parameters. This will enjoy frequent use in other categories of applications. It may be augmented as desired to indicate such items as in situ monitoring sites, locations where control or corrective measures are in effect, sites where particular adverse impacts are occurring, and potential trouble spots.

Impact Assessment

The assessment of environmental impact from pollution is beset with a great many unknowns. It would be either naive or deceptive to suggest that remote sensing is the answer to these exceedingly complex problems. If we think of ultimate impact in terms of chemical, physiological, psychological, or other "micro" effects, then perhaps remote sensing can make few direct contributions. Knowledge of impacts at this level is of limited value, however, without information about interactions at a more "macro" level. This involves determinations of the distribution of pollution-related stresses in space and time and in relation to the distribution of environmental components likely to be impacted by these stresses. It also includes evaluations and projections of the "macro" responses of the impacted environmental components--e.g., population movements, changes in land use or occupational practices, eutrophication of water bodies, or loss of vigor of vegetation. It is at this level that remote sensor imagery analysis can make very significant contributions.

A useful first step would be the careful study of the previously prepared map or mosaic in conjunction with overlays generated during the environmental analysis. This will permit the analysis team to see and evaluate the distribution and types of identified pollution sources with respect to watersheds and drainage patterns, airsheds (if this information is available), geology and physiography, soil types, population distribution, land use distribution, crops and natural vegetation, wildlife and fish habitats, etc. The clues and inferences derived from this exercise can be further refined by careful, selective study of the airphotos or other appropriate remote sensor imagery. As before, the imagery study can suggest locations for remote sensor flights or ground observations to supply more definitive information at selected sites.

We need not include here a long list of possible considerations in assessing environmental impact using remote sensing techniques. Many of these will not surface anyway until a specific area and its specific problems are addressed. However, brief discussion of one class of considerations might be warranted as an example--i.e., those associated with water-borne pollution. A detailed surface drainage map or overlay is an early product of an environmental analysis. Using this, it is rather straightforward, but important, to say whether a given location will or will not be directly affected, in terms of surface drainage, by contaminants from such diverse sources as industrial plants, mines, feedlots, pesticide-treated fields, and refuse dumps. Subsurface drainage is much trickier. Water in this system may make its way back to the surface at a lower elevation or stop in some local water table. In either case it also is important in terms of pollution hazards. To understand subsurface flow we need good information about geology and soils, much of which can come from the imagery analysis. On the receiving end of the impact, we need to know about such things as locations of drinking water sources, water-related recreational activities, subsistence and commercial fishing, and the ecology of the affected water bodies. Again, to varying degrees, remote sensing can contribute to the answers.

Controls and Monitoring

Based on the information previously compiled on locations and types of sources and their probable or certain impacts, controls and corrective measures will be indicated. In some cases the imagery analysis may be a useful tool even at this step. This might especially be the case if there is a question of relocating a source.

At any rate, once the controls are imposed, means must be established for monitoring the offending site to assess changes indicative of the effectiveness of the control measure and to gain legal evidence, if need be. This is a job primarily for *in situ* sensors and for some of the more specialized remote sensing systems.

Projections of Trends and Potential Problem Areas

Environmental impact is a dynamic process, usually having both short- and long-term components. Our ability to project potential trouble spots and future impacts depends on how thoroughly we have grounded ourselves in an understanding of fundamental environmental relationships. Many of the same considerations used in predicting current sources and impacts will likewise be useful in addressing future problems. One important ingredient of future impact projection is the assessment of key sociological trends. Of course this is a difficult task. However, the basic environmental analysis, including careful study of sequential imagery, should provide a sound basis for intelligent extrapolation of past and present social patterns and changes and related environmental stresses to the future.

To help in assessing and minimizing future pollution problems, it is necessary to establish current base line data and to update these data periodically in order to detect trends and rates of change. These base line/monitoring sites might be placed in two general categories: (1) locations where problems already exist, and where control measures may or may not have been applied; and (2) locations having no current pollution problems, but where likely or certain pollution impacts will occur in the future. In either case, analysis of remote sensor imagery can be of considerable benefit both in establishing optimum locations for these sites and in deriving much of the pertinent base line and periodic data.

Preventive Measures

Insofar as possible, the best corrective measure for potential problem areas is to prevent or minimize the problem in the first place. Technological advances in pollution control, waste disposal, etc., should prove very important in this regard. An additional important consideration is the location of anticipated pollution sources with respect to environmental factors having a significant bearing on the degree of impact. Very careful thought should precede the placement of an actual or potentially important pollution source in a fragile environment or in a location where detrimental impacts could be far-reaching. Planned refuse dumps should be located to minimize adverse health and aesthetic impacts. In the location of dumps as well as a wide variety of other sources, surface and subsurface drainage characteristics should be carefully considered. Numerous other examples could be cited. All these might be placed in the general categories of development planning and site selection. Remote sensor imagery analysis is eminently amenable to such planning activities.

Not all significant pollution sources are chronic and thus semi-predictable. Occasionally pollutants are unleashed catastrophically. An environmental analysis of an area where the possibility of such a crisis exists, completed beforehand, can provide a better basis for immediate assessment of potential impact and appropriate emergency measures, should the crisis arise.

Research

Research needs are implicit in all the categories of applications mentioned here. Remote sensing can serve as a highly effective tool in many of the research programs in which EPA is and will be involved. This will have spinoff benefits in improving the use of this tool for applications. Of course, the need also exists for research efforts geared specifically to improving the utility of remote sensing technology and methods in these applications.

CONCLUSIONS

The ideas presented here are not startlingly new. They are based largely on common sense, and put together in a way which we hope will provide a useful broad framework for the utilization of remote sensing in problems confronting the EPA. Essentially the framework provides for the derivation of basic information necessary for an understanding of complex environmental relationships, using remote sensing as the focal point, followed by the application of this information to problems of immediate and long-range concern. As straightforward as this approach seems, it is not being used anywhere near its potential in addressing environmental problems.

Our discussion of EPA applications in this paper has necessarily been somewhat hypothetical. More specific and more useful procedures relevant to these applications are bound to emerge from the actual functioning of a skilled imagery analysis team motivated to seek answers to real, urgent problems in a real environmental setting.

AERIAL SPILL PREVENTION SURVEILLANCE DURING SUB-OPTIMUM WEATHER

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ABSTRACT

An oil and other hazardous materials spill prevention surveillance system has been developed for use during sub-optimum aerial photographic weather conditions. For sky cover and visibility conditions thought to be representative of the nearly infinite range of weather possibilities under which multi-band aerial photography was acquired, only a highly sensitive color positive film provided consistently interpretable results.

Rapid access techniques were also evaluated resulting in recommendations for a tactical data acquisition system for both real-and near real-time information update during sub-optimum aerial photographic weather conditions.

INTRODUCTION

It is widely recognized that aerial photography, flown to strict specifications, can provide vital information quickly and economically on the location, quality and quantity of various components of the natural environment. Welch, et al, (1972) showed that aerial photography could be used to identify potential sources of environmental damage from accidental spills of oil and hazardous materials, and that such information could be used in spill prevention.

Welch demonstrated that under optimum aerial photographic weather conditions, high altitude color infrared photographs taken at scales of 1/40,000 to 1/60,000 were useful in regional surveys for locating industrial activities that could be expected to product spills of oil and other hazardous materials. After these areas were delineated on small scale photographs, color aerial photography flown at larger scales of 1/5,000 to 1/10,000 could be taken of selected areas for more detailed analysis in order to locate specific potential threats and actual spills. Strategic information gained in this manner could be used to prevent spills by early detection of careless practices which could lead to undesirable releases of oil and hazardous materials into waterways.

It is frequently the case that circumstances necessitating a tactical approach to data gathering combine to present an update problem at a time when weather conditions are not truly suitable for aerial photography. For example, an extended heavy rainfall could produce flooding and soil saturation, jeopardizing earthen revetments. Such a protracted storm is also likely to result in residual cloud cover, necessitating a delay in updating unless specific procedures for such an eventuality have been previously defined.

Existing camera systems, films, filters, and processing and interpretation techniques can be manipulated in a variety of ways to provide acceptable photography under various weather conditions. In investigating these methods for use in spill prevention, it was hypothesized that even in critical situations where weather was not ideal, acceptable aerial photography could be obtained.

This study was undertaken to provide a means for acquiring high quality information for spill prevention under a variety of sub-optimum aerial photographic weather conditions. Optimum conditions are defined for this purpose to be clear skies with at least 15 miles horizontal visibility. Thus, the term "sub-optimum weather conditions" applies to any situation resulting in sky cover (clouds) or reduced visibility that may restrict aerial photography operations. In addition, several rapid access techniques useful for minimizing the time necessary for acquisition and dissemination of useful information were investigated.

METHODS

Cloud and haze conditions under which aerial photographic surveillance was to be attempted were chosen so as to be representative of conditions which commonly occur over industrial areas. Weather parameters considered were divided into two categories -- clouds and haze -- each of which offers different problems in acquisition of high quality photography. For this study, haze is considered to describe a general set of circumstances resulting in decreased horizontal visibility due to smoke, dust, photo-chemical smog or other particulates, but differing from, although frequently occurring with clouds. Further, interaction between sun angle (angle above horizon) and haze was analyzed because the effective path length of the illuminating source (a function of angle above the horizon) is critical in selecting photographic parameters. In heavy haze, the difference of a few hours in mission scheduling may allow considerable more flexibility in photo acquisition as haze may dissipate.

Table 1 summarizes the cloud and visibility conditions chosen for analysis. The conditions were considered to be representative increments of weather conditions which vary continuously over a nearly infinite range. The increments specified were utilized as data acquisition guidelines in attempting to analyze the effects of combinations of the weather types listed on interpretability of ground features.

TABLE 1

CLOUD AND VISIBILITY CONDITIONS UNDER WHICH PHOTOGRAPHS WERE ACQUIRED FOR THIS STUDY

	Cloud Base (Height in feet)			
Sky Cover (Amount in tenths)	1,000	5,000	10,000	20,000+
Overcast (10)	X	X	X	X
Broken (5-9)	X	X	X	X
Scattered (1-4)	X	X	X	X

	Sun Angle (Degrees above horizon)		
Haze Type (visibility in Miles)	20°	40°	60°
Medium (2-4)	X	X	X
Heavy (<2)			X

Previous work by Welch, et. al. (1972), was used to specify three film-filter combinations for testing: (color Kodak film type SO-397 or equivalent) with a Wratten 1A filter; color infrared (Kodak Aerochrome Infrared, film type 2443 or equivalent) with a Wratten 12 filter; and panchromatic (Kodak Plus X film type 2402 and Panatomic-X film type 3400 or equivalent) with no filter. A three camera vertically mounted array of 70mm Hasselblad 500EL cameras was used as the primary data acquisition system.

The requirements of detailed photo interpretation as well as cloud ceilings imposed by sub-optimum weather conditions necessitated the acquisition of photos at scales 1:5,000 or greater. Flight lines were located over three test areas in the San Francisco Bay region where sufficient aerial photography and ground truth data were available from previous work to eliminate the need for detailed surface observations.

In the performance of the rapid access test, it was assumed that data similar to that obtained during the sub-optimum weather condition tests were needed quickly. Rapid film processing techniques for both color and black-and-white were investigated.

Detailed interpretation was performed independently by three trained photo interpreters to determine the merits of each film-filter combination under the weather conditions encountered for this test. Eight classes of features were examined: counting of storage tanks; leaks or seepage; oil on water; condition of dikes; trash and debris; effluents; water quality; and tracing pipelines (Figures 1, 2, and 3). Ratings were recorded for the photographic quality of the imagery and the interpretability of the preselected features.

FIGURE 1

Vertical aerial photo of a steel salvage facility at Richmond, California. Careless practices in handling waste materials along shoreline are evident in this panchrometic photo taken from a 1,300 foot flight altitude under a 5,000 foot overcast cloud base. Note absence of shadows and low relative contrast typical of photos taken under overcast sky conditions. (Plus-X 70mm, no filter, Hasselblad 500 EL camera, 1/500 f 2.8)

FIGURE 2

Waste water and oil storage pond from ship bilge pumping operations at Richmond, California. San Francisco Bay Shoreline is at lower right of photo. Note reflection of photographic aircraft on oil slick at photo nadir. This situation verifies that oil slicks reflect the sky above. At this latitude (40°N) the sun does not reach zenith, therefore, the image is not the shadow of the aircraft. It is possible to detect oil slicks on an overcast day with relatively greater ease than on a clear day because of the reflectance of the clouds by the oil slick. (Aircraft altitude 750 feet, overcast cloud base at 800 feet, Plus-X 70mm, no filter, Hasselblad 500 EL camera, 1/500 f 4).

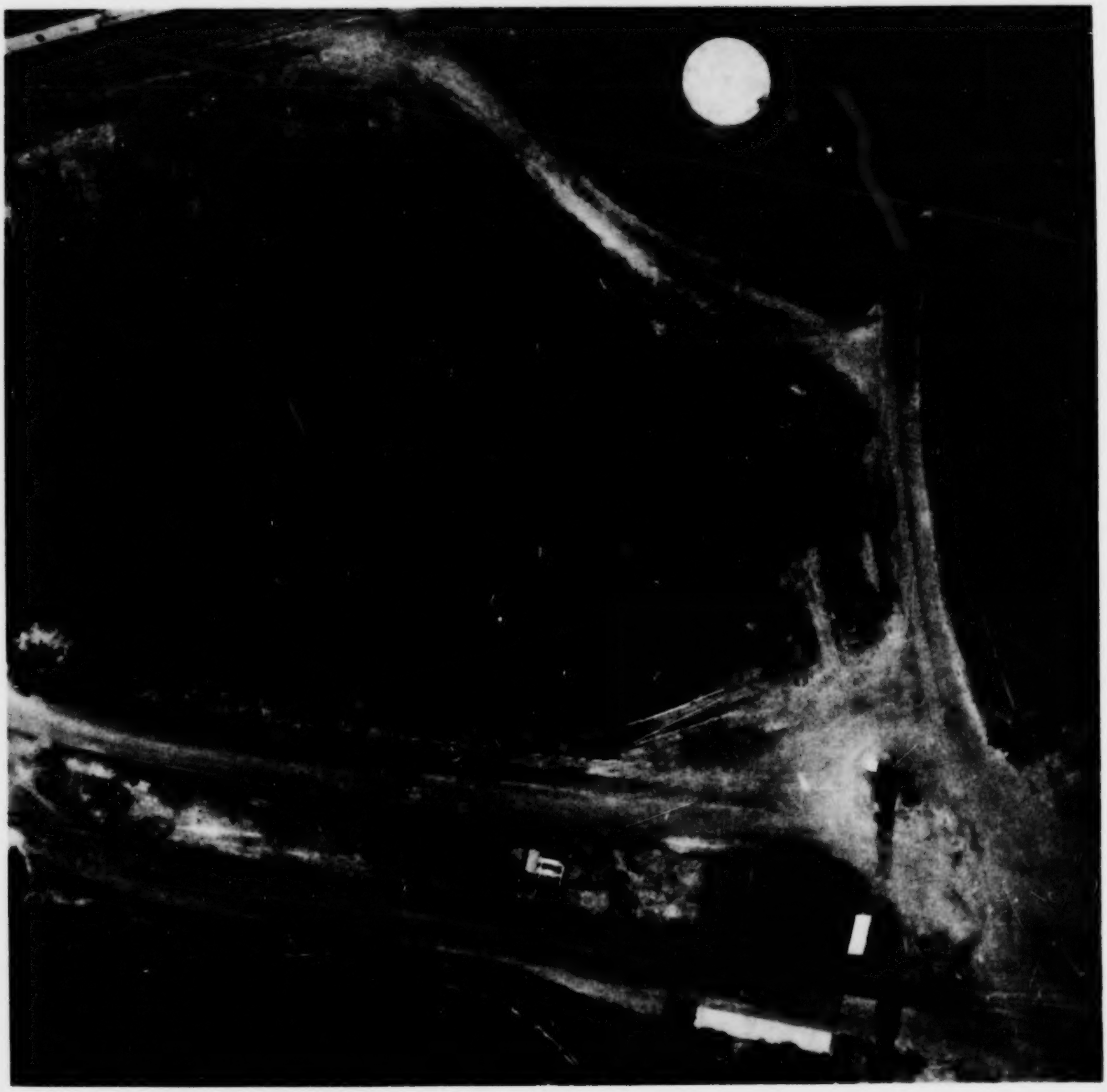

FIGURE 3

Petroleum refinery at Avon, California. Detailed photo interpretation of refinery facilities that might be a spill threat to a nearby waterway can be performed on this image taken under an overcast sky. Stereoscopic interpretation of this image permits evaluating the integrity of protective facilities - levees, barricades and revetments - that are associated with refinery storage tanks and pipelines. (Aircraft altitude 1,300 feet, overcast cloud base at 5,000 feet, Plus X 700mm no filter, Hasselblad 500EL camera, 1/500 f 2.8).

DISCUSSION AND CONCLUSIONS

In comparison to the other film/filter combinations tested, only positive color film (exposed through a Wratten 1A filter) provided adequate image quality regardless of time of coverage, weather conditions, or reasonable deviation from optimum exposure settings. In fact, Kodak SO-397 aerial color film apparently can be utilized under any daylight conditions where an aerial photographic mission can be safely attempted. The wide exposure latitude of this film combined with comprehensive flight planning adds the necessary tactical dimension needed to maintain a dynamic information file based on the strategic surveillance system specified in Welch, et al. (1972). Color infrared and black-and-white panchromatic films that have specific surveillance applications in clear weather exhibited shortcomings which warrent recommendation against their use under less than optimum weather.

Constraints on both the photographic system and on aircraft operations are more severe under sub-optimum weather conditions. The pilot must consider ceiling height and horizontal visibility as well as aircraft speed in order to successfully obtain low altitude photography. As altitude decreases image motion increases unless there is a compensating decrease in aircraft speed. Aircraft safety must be a major consideration in mission planning, its impact depending to a limited extent on the urgency of the mission.

Careful planning by the photographer is also required. To insure correctly exposed film and maximum possible data content, his planning should be based on a reliable source of weather information. Clouds, suspended particulates precipitation, shadows and non-uniform illumination all require careful consideration, along with the usual factors of target characteristics and product requirements.

The importance of weather to the safety and performance of the photographic mission necessitates a source of timely, accurate weather information. Both forecasted and observed conditions for the target vicinity as well as the routes of ingress and egress should be available. FAA flight service facilities along the flight path provide a good source of enroute weather. For weather over the target the ideal source is an on-site observer in radio contact with the aircraft. Comprehensive weather information will help both pilot and photographer to perform their respective jobs effectively.

The preferred surveillance system for use under sub-optimum weather conditions is a single-engine, high-wing monoplane carrying in vertical mode an aerial camera of format size suitable to the desired altitude, low speed operation necessitated by operation under low clouds. The high-wing configuration is preferred because it simplified the problem of visually aligning the aircraft on a perdetermined flight line. An acquisition scale of 1:5,000 provides adequate detail provided a high quality camera system is chosen.

In situations requiring real-time or near real-time assessment of transient conditions, such as natural disasters or catastrophic spills a properly employed rapid access photographic system can meet most information requirements which could be addressed in a routine situation by aerial photography. A rapid access operation requires coordination in all phases, but can significantly reduce the elapsed time between exposure and information dissemination. Major time reductions can be accomplished by collating the film processing, interpretation, and dissemination facilities and if possible, by overlapping processing and transport functions.

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ACKNOWLEDGEMENT

This work was sponsored by the Environmental Protection Agency contract Number 68-01-1091. The authors wish to acknowledge the support and guidance of Mr. J. Riley, EPA Project Officer. Other EarthSat personnel who contributed to this project included Dr. R. Colwell and Messers. R. Temple, and S. Daus.

SESSION VI

OIL AND HAZARDOUS MATERIALS SENSORS

CHAIRMAN

MR. DONALD R. JONES

DIVISION OF OIL & HAZARDOUS MATERIALS, OAWP

Title:

Single Wavelength Fluorescence Excitation for On-Site Oil Spill Identification

Abstract:

This communication discusses the use of improved fluorescent techniques to field-classify and fingerprint oils by employing a single, fixed, excitation wavelength (254 nm) to generate characteristic oil fluorescence spectra. The effects of sample preparation and weathering of the spilled oil on the fluorescent fingerprint are presented. One of several oil spill incidents to which this approach has been successfully applied is discussed in detail. In light of these findings fluorescent spectroscopic techniques are ideally suited for rapid field identifications of spilled oils.

Disclaimer:

The contents of this report represent the findings and views of the author who is responsible for the facts and accuracy of the data presented. The paper does not necessarily reflect the official views or policy of the U. S. Coast Guard.

Author:

J. Richard Jadamec

INTRODUCTION

Present oil spill investigation procedures involve the collection and transmittal of oil spill and suspect source samples to a laboratory for analysis. This procedure results in a considerable time delay in identifying the spill source. This could be avoided if field personnel had the capability to classify or identify oils directly. Identification of the source responsible for an oil spill can be accomplished by either quantitative or qualitative methods. A qualitative method is required to develop a field capability; a method in which no separation or discrete determination of oil components is required. This approach is known as a fingerprint method, wherein the oil is analyzed by a suitable technique to obtain a characteristic fingerprint or signature without any chemical or physical separations being employed other than freeing the oil from water or other debris.

Previous investigations by Coakley[1], Fantasia, et.al.[2], Thurston, et.al.[3], Gruenfeld[5], McKay, et.al.[5], among others, have shown that fluorescent spectroscopic techniques are directly applicable for the detection, identification, and analysis of oils. These investigations have demonstrated that fluorescence techniques are not only rapid, but are very specific in their ability to fingerprint oils. The above mentioned studies have employed a variety of excitation wavelengths, data processing, and experimental conditions which at first glance are not directly applicable for field deployable instrumentation. This communication discusses the use of fluorescence techniques to field classify and perhaps fingerprint oils by employing a single, fixed, excitation wavelength, (254 nm) to generate characteristic fluorescence spectra. Previous investigators, Parker, et.al.[6] and Levy[7] have shown that oils have a strong absorption in the short wavelength ultraviolet region. Parker, et.al.[6] observed that oils had absorption spectra similar in response to their excitation spectra, with the maximum absorption being at 238 nm and subsidiary maxima at 253 to 263 nm and 286 nm. These same areas were verified by Levy[7] in a recent report employing ultraviolet absorption techniques to identify petroleum oils. Initial spot screening of oil samples, by ultraviolet absorption, obtained for this study confirmed the 238 nm maximum absorption and also the presence of a secondary 255 nm abosrption region for all oils screened. Little or no absorption was observed at 286 nm or longer wavelength regions for some oils. Realizing that a fluorescence signal is preceded by the absorption of radiant energy, the common, but not excessive, absorption in the 254 nm region for all oils was selected as a possible single excitation level for all petroleum samples.

EXPERIMENTAL:

Apparatus: All fluorescence emission spectra were obtained using a Perkin-Elmer MPF-3 Fluorescence Spectrophotometer, equipped with a 150 watt xenon lamp and Model QPD-33 recorder. All spectra were recorded at a fixed excitation and emission spectral band width of 34 nm and 1.5 nm, respectively.

Solvents: Spectroquality (MCB) cyclohexane was used throughout this study.

Procedure: All spectra were recorded at a constant concentration of 1/10,000, weight to weight, petroleum to cyclohexane. All samples were stored in low actinic glass volumetrics prior to analysis. In the recording of all fluorescence spectra the maximum fluorescence signal for each oil studied was normalized to 95% of the recorder scale.

Results & Discussion

Figures 1 and 2 show the fluorescent emission spectra of five different oils when excited at 254 nm and 290 nm respectively. It is obvious that excitation at 254 nm produces a greater variability in the character of the fluorescent emission spectra. Table 1 summarizes the fluorescent data for 16 of the crude and refined petroleum oils assembled for this study. This cross section of oil types is tabulated listing the wavelengths of the major and minor fluorescent responses for each oil. The minor responses are listed, from left to right in decreasing order of amplitude. Viewing this tabulated data it appears possible to index oils as a function of fluorescent peak responses when a constant excitation energy is used. In cases where oils have similar peak responses as shown in Figures 3 and 4, the use of peak ratios, a technique used earlier by Thurston, et.al.[3], may be of value.

Assuming that the field party had an oil index, based on fluorescent spectral responses and peak ratios, the question then arises as to the reproducibility of spectra with respect to sample preparation and oil weathering. Investigations on the dependence of fluorescence spectra with respect to sample preparation are shown in figures 5, 6, and 7. Initial studies were made at a constant oil to solvent ratio of 1 to 10,000. Realizing that this type of control is not feasible for direct field application, investigations were conducted on the dependence of fluorescent signature with respect to variations in oil/solvent concentration ratios. Figures 5, 6, and 7 show the variation of estimated oil/solvent concentration with respect to controlled concentrations.

Figures 5 and 6 indicate that the fluorescent signature is unchanged for a marine lube and number 4 fuel oil, respectively, and it can readily be seen that if the amplitude of each respective maximum was normalized to 95% the spectra would be identical. Figure 7, a marine diesel oil, shows a slight variation in spectral response, but still retains its basic fluorescent signature in a reverse order. Similar results were obtained in studies using a cross section of oil types as listed in Table 1.

Preliminary studies on the weathering of thick and thin oil films indicates that weathered oils may be correlated directly with unweathered oils, in many cases. As observed earlier by Coakley[1] and Thurston, et.al.[3], the fluorescent spectral fingerprint of an oil is not significantly affected by weathering processes, but the fluorescent signal strength decreases as a function of weathering time. Present weathering studies in progress involve the weathering of a thick, 0.15 mm, and thin, 0.03 mm, oil layers at one month and two week exposures to the environment, respectively. Figures 8 and 9 show, respectively, the effects of weathering on the fluorescent fingerprint of a number 2 fuel oil, and marine lube oil. Variations do exist in the fluorescent fingerprint of some oils, but it is felt that these variations will not affect the rapid field identification of oils. Other oils, for example a number 5 and 6 fuel oil, and a Venezuela crude had no significant changes in their fluorescent signature. As stated previously, the fluorescent signal strength decreases with weathering time. In this study, the decrease in signal strength has been minimized by normalizing the maximum fluorescent signal to 95% of recorder scale before recording the spectrum of each oil.

Another possible field application would be the identification of a spill source. Initially field investigation units could identify the type of oil present and indicate prime spill source candidates. Utilizing the fluorescent fingerprint or signature of the spilled oil they could then match it with that of a suspect source. This approach has been used successfully in real spill investigations. Figure 10, represents one particular spill situation. One of eight vessels was suspected of pumping its bilges and being responsible for an oil spill incident. A total of twenty-three samples was collected and transferred to a laboratory for analysis. Nineteen of these collected samples had fluorescent fingerprint drastically different from the spill fingerprint. Three of the four fluorescent fingerprints shown in Figure 10 are nearly identical. One suspect fingerprint is a direct overlay of the spill fingerprint. A second suspect fingerprint differs slightly. If the field unit had been equipped with portable instrumentation, the identification of the spill source could have been made directly in the field, or it could have resulted in the transmittal of only four samples to a laboratory for detailed analysis. The identification by fluorescent fingerprinting in the above mentioned case, was confirmed by infrared, gas chromatography, simulated distillation gas chromatography, and atomic absorption analysis.

CONCLUSIONS

Identification and fingerprinting of oils by fluorescent techniques directly in the field, at the site of an oil spill, appears feasible. Utilization of a single wavelength excitation source, such as a line filtered mercury lamp, appears sufficient to generate characteristic fluorescence spectra for a variety of oils. Sample preparation and short term weathering of oils do not significantly affect the fluorescence fingerprint or signature of an oil. Investigations are currently in progress to develop these fluorescent techniques and instrumentation for direct field application.

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TABLE 1

Oil Type	API Gravity	Major	Wavelengths of Maximum and Minimum Fluorescence Responses in Nanometers Decreasing Minima			
No. 6 Fuel Oil	11.4	379	364	406	431	337
Crude Oil - Bartlet Field	15.0	358	373	386	346	400
Crude Oil - Lago	18.0	360	373	335	427	316
Marine Lube Oil	21.8	332	318	346	354	373
Marine Diesel	25.2	333	347	318	355	374
Crude Oil - Monument Buttee	26.2	360	373	338	316	425
10W-30 Motor Oil	30.0	332	344	312	293	370
Hydraulic Oil	31.6	332	345	311	293	369
No. 2 Fuel Oil	35.0	331	314	340	350	366
No. 4 Fuel Oil	35.0	357	351	336	316	374
No. 5 Fuel Oil	35.0	358	373	346	404	432
Crude Oil - Zuitina	41.0	357	372	347	336	316
Jet Fuel	45.0	326	336	290	303	349
Crude Oil - East Blackburn	54.2	310	326	342	354	356
Gasoline	--	290	322	326	336	352
Kerosene	42.1	305	326	315	291	336

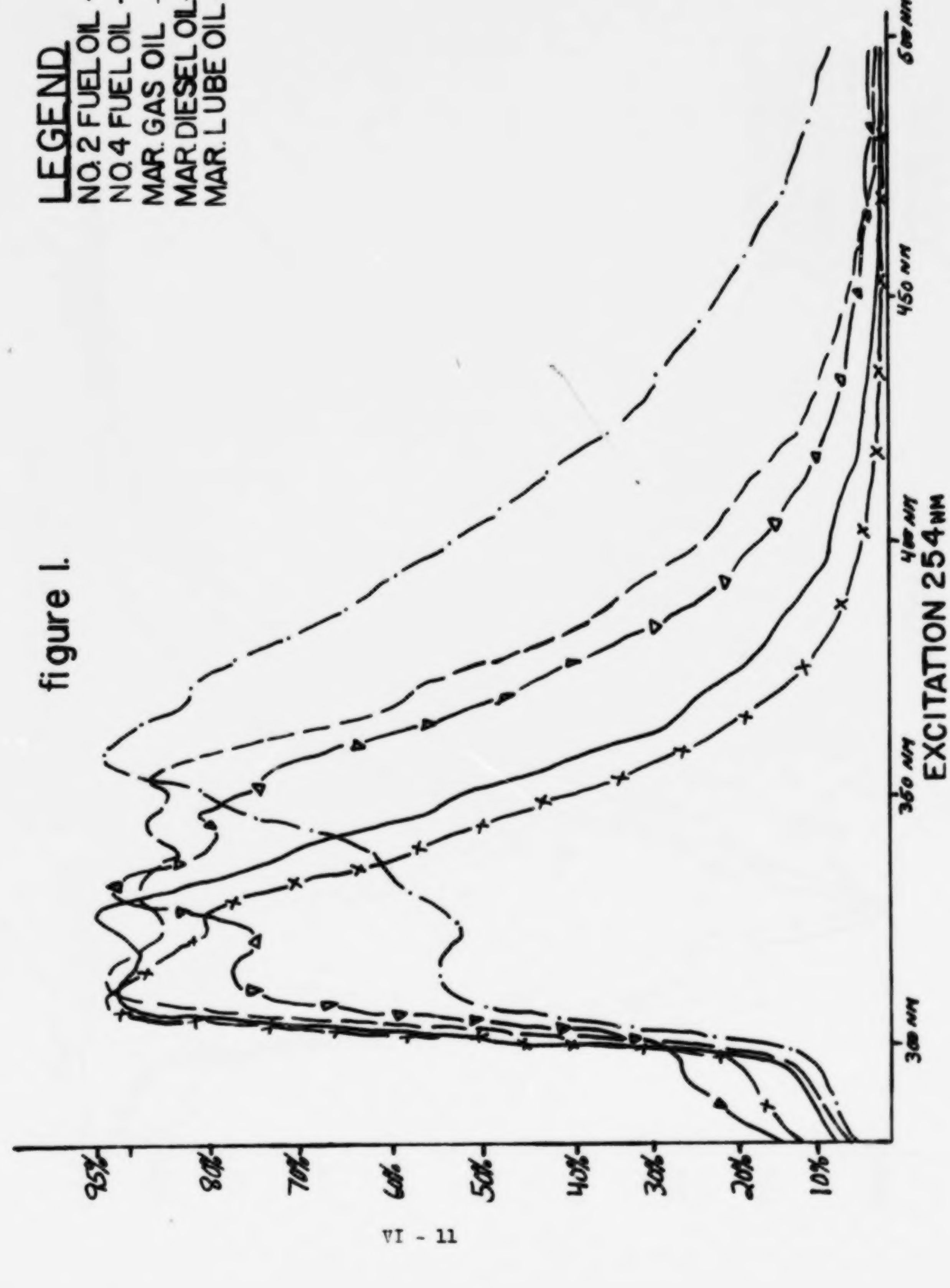
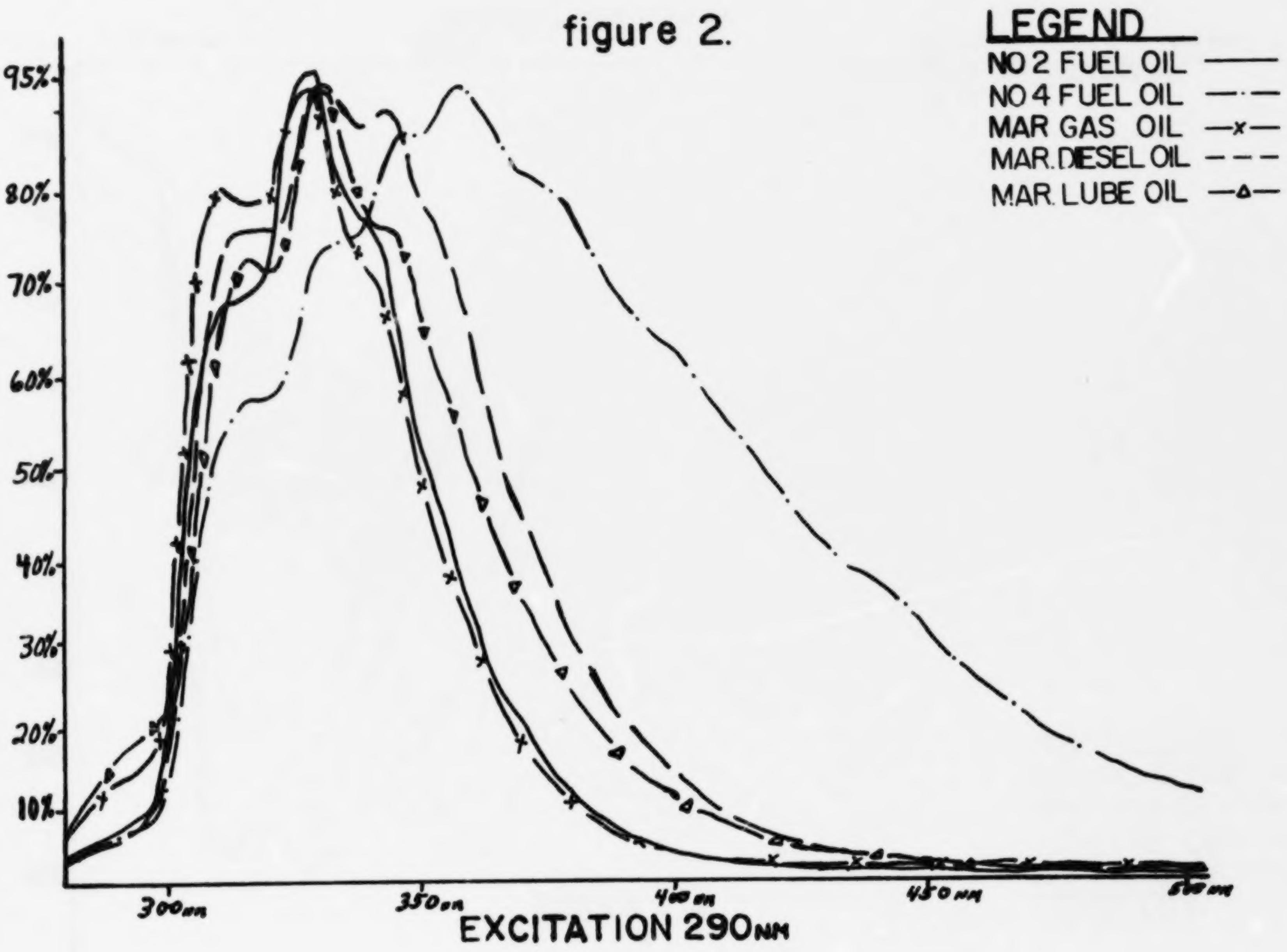

LEGEND
NO.2 FUEL OIL
NO.4 FUEL OIL
MAR. GAS OIL
MAR. DIESEL OIL
MAR. LUBE OIL
95%
80%
70%
60%
50%
40%
30%
20%
10%
300 NM
350 NM
400 NM
450 NM
500 NM
EXCITATION 254NM

figure 1.

figure 2.


LEGEND
NO 2 FUEL OIL ——
NO 4 FUEL OIL —·—
MAR GAS OIL —x—
MAR. DIESEL OIL - - -
MAR. LUBE OIL —△—
95%
80%
70%
60%
50%
40%
30%
20%
10%
300nm
350nm
400nm
450nm
500nm
EXCITATION 290NM

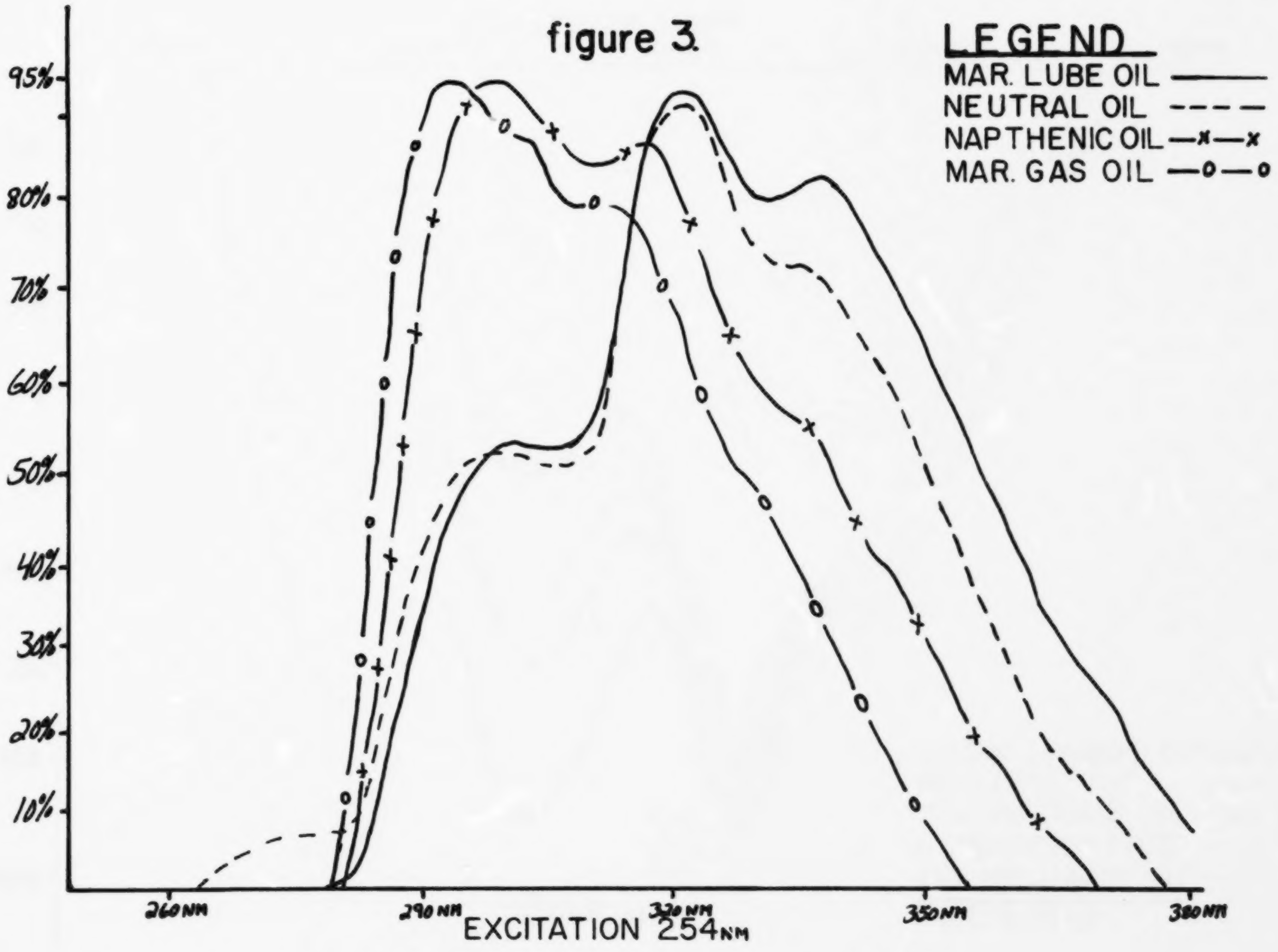
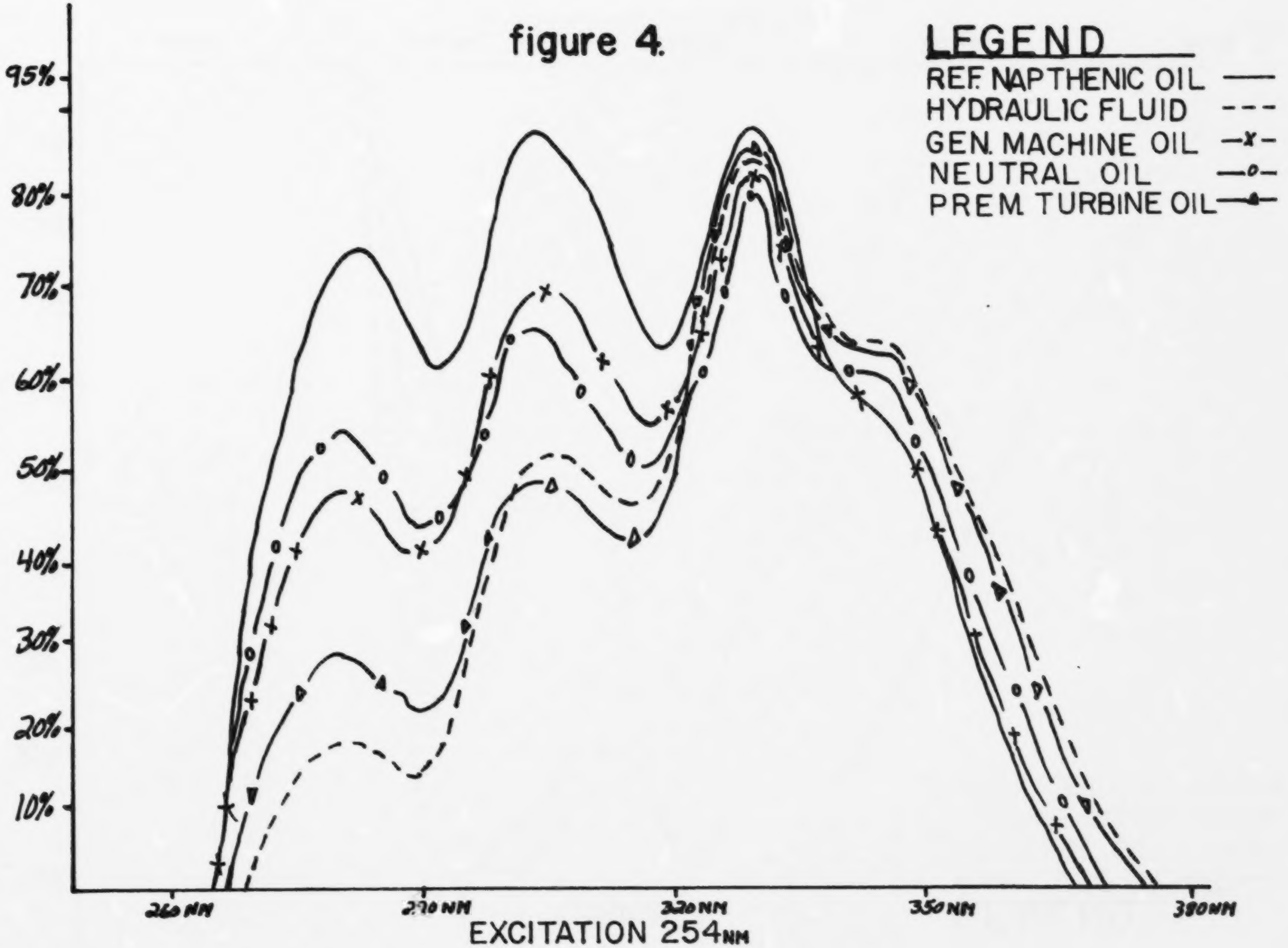


figure 3.

LEGEND
MAR. LUBE OIL
NEUTRAL OIL
NAPTHENIC OIL —x—x
MAR. GAS OIL —o—o
95%
80%
70%
60%
50%
40%
30%
20%
10%
260NM
290NM
320NM
350NM
380NM
EXCITATION 254NM

figure 4.


LEGEND
REF. NAPTHENIC OIL
HYDRAULIC FLUID
GEN. MACHINE OIL
NEUTRAL OIL
PREM. TURBINE OIL
95%
80%
70%
60%
50%
40%
30%
20%
10%
260 NM
290 NM
320 NM
350 NM
380 NM
EXCITATION 254 NM

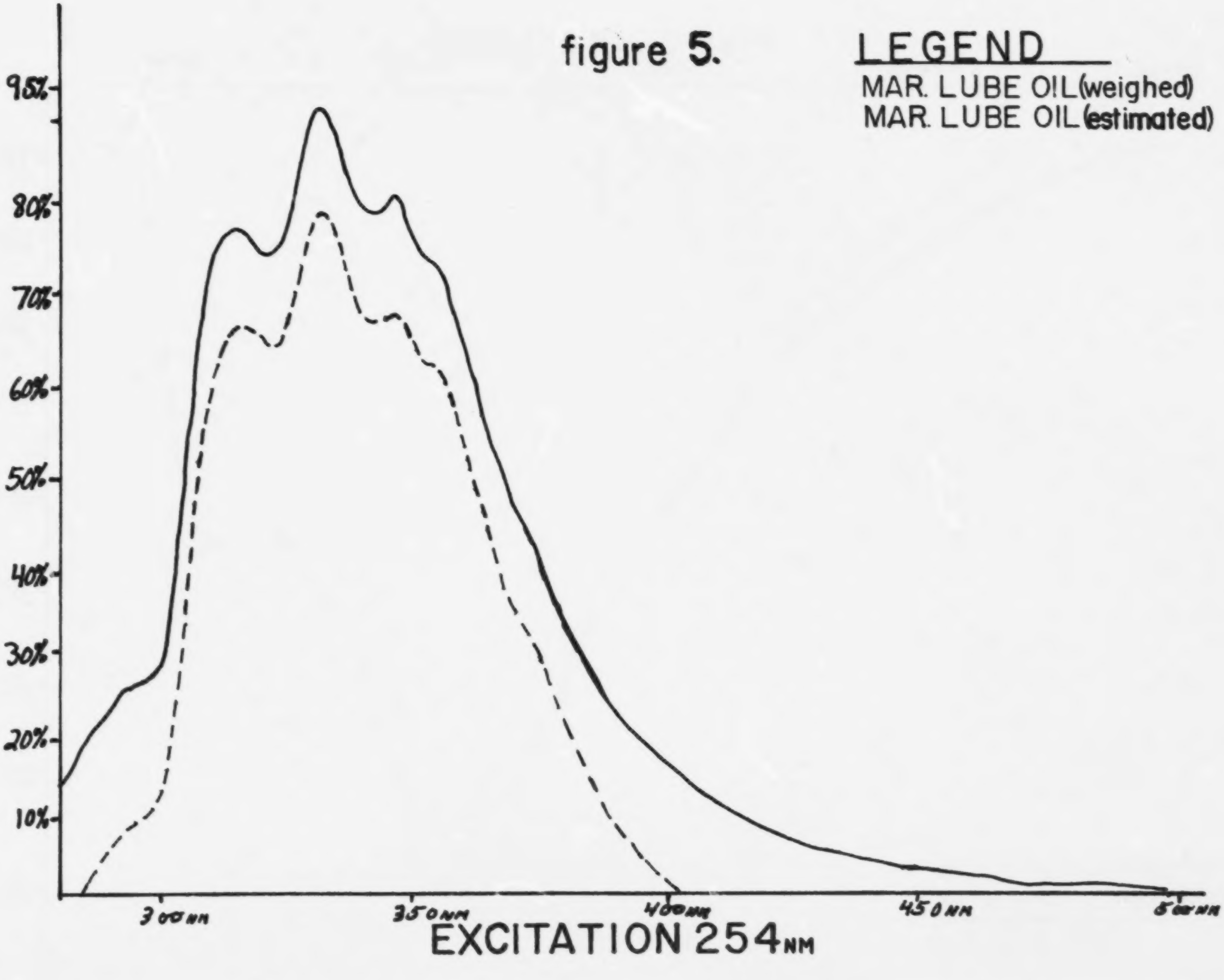
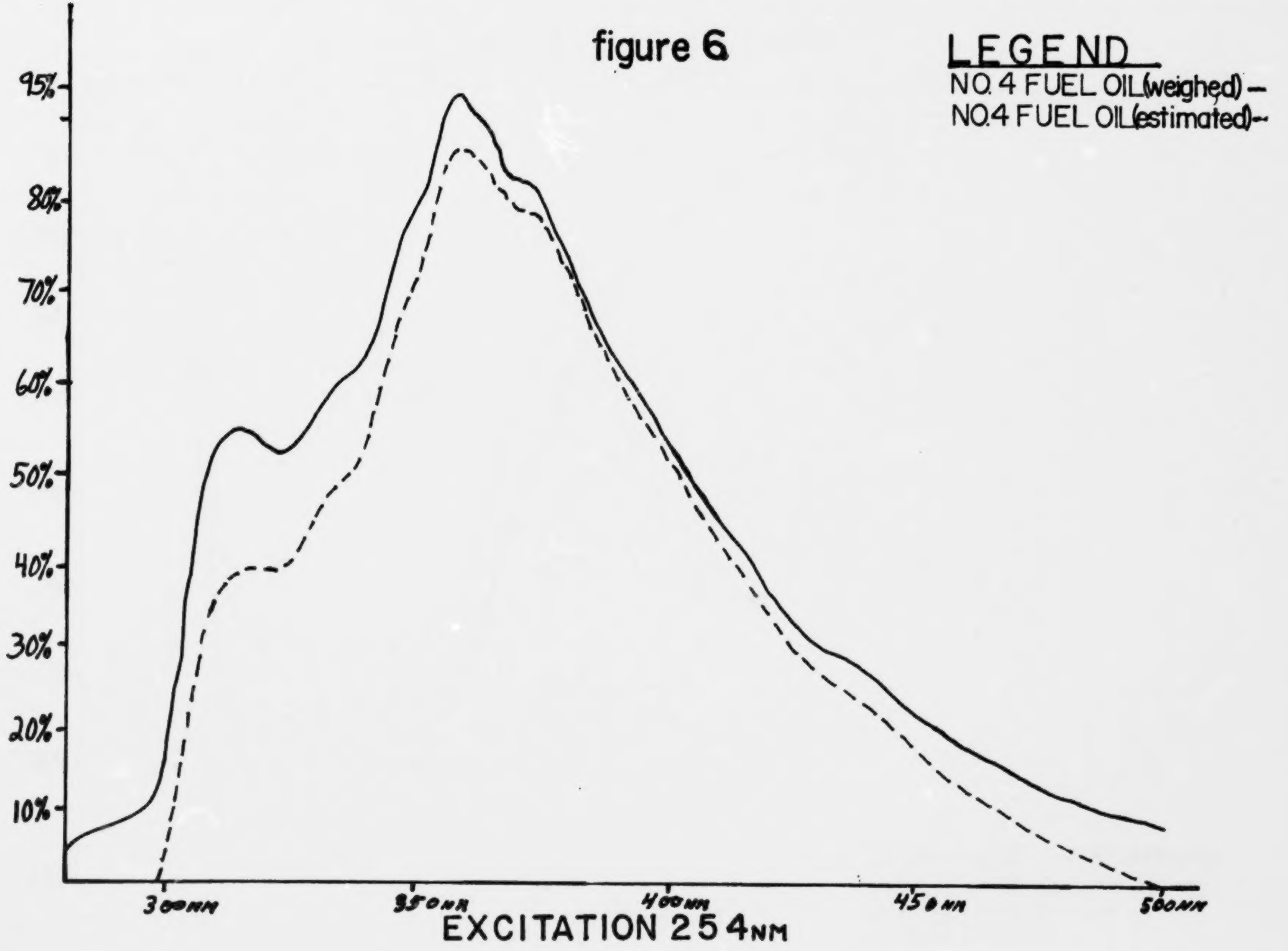


figure 5.

LEGEND
MAR. LUBE OIL(weighed)
MAR. LUBE OIL(estimated)
95%
80%
70%
60%
50%
40%
30%
20%
10%
300NM
350NM
400NM
450NM
500NM
EXCITATION 254NM

figure 6


LEGEND
NO. 4 FUEL OIL(weighed) —
NO.4 FUEL OIL(estimated)--
95%
80%
70%
60%
50%
40%
30%
20%
10%
300NM
350NM
400NM
450NM
500NM
EXCITATION 254NM

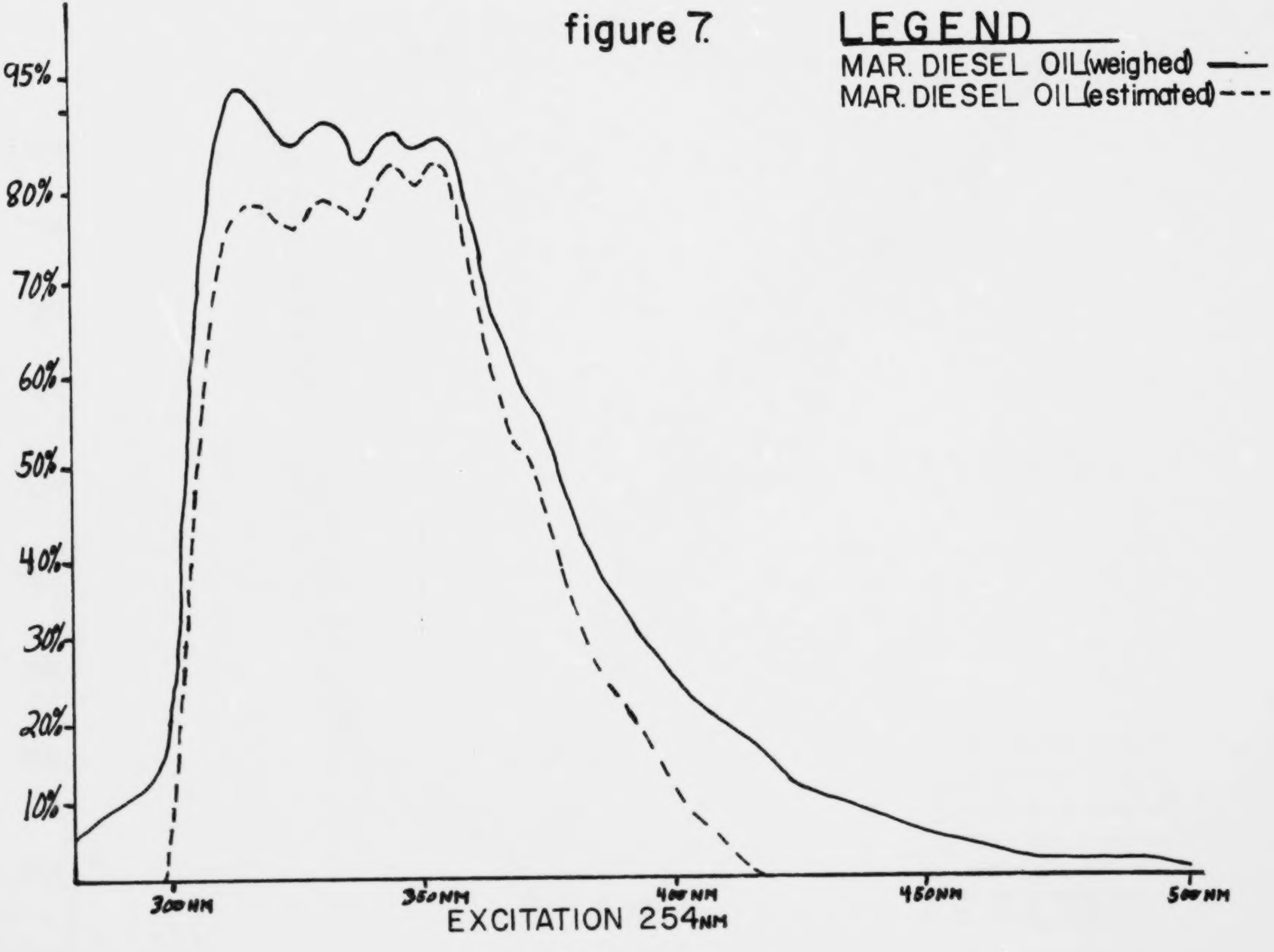


figure 7.

LEGEND
MAR. DIESEL OIL(weighed) ——
MAR. DIESEL OIL(estimated) - - -
95%
80%
70%
60%
50%
40%
30%
20%
10%
300NM
350NM
400NM
450NM
500NM
EXCITATION 254NM

figure 8.

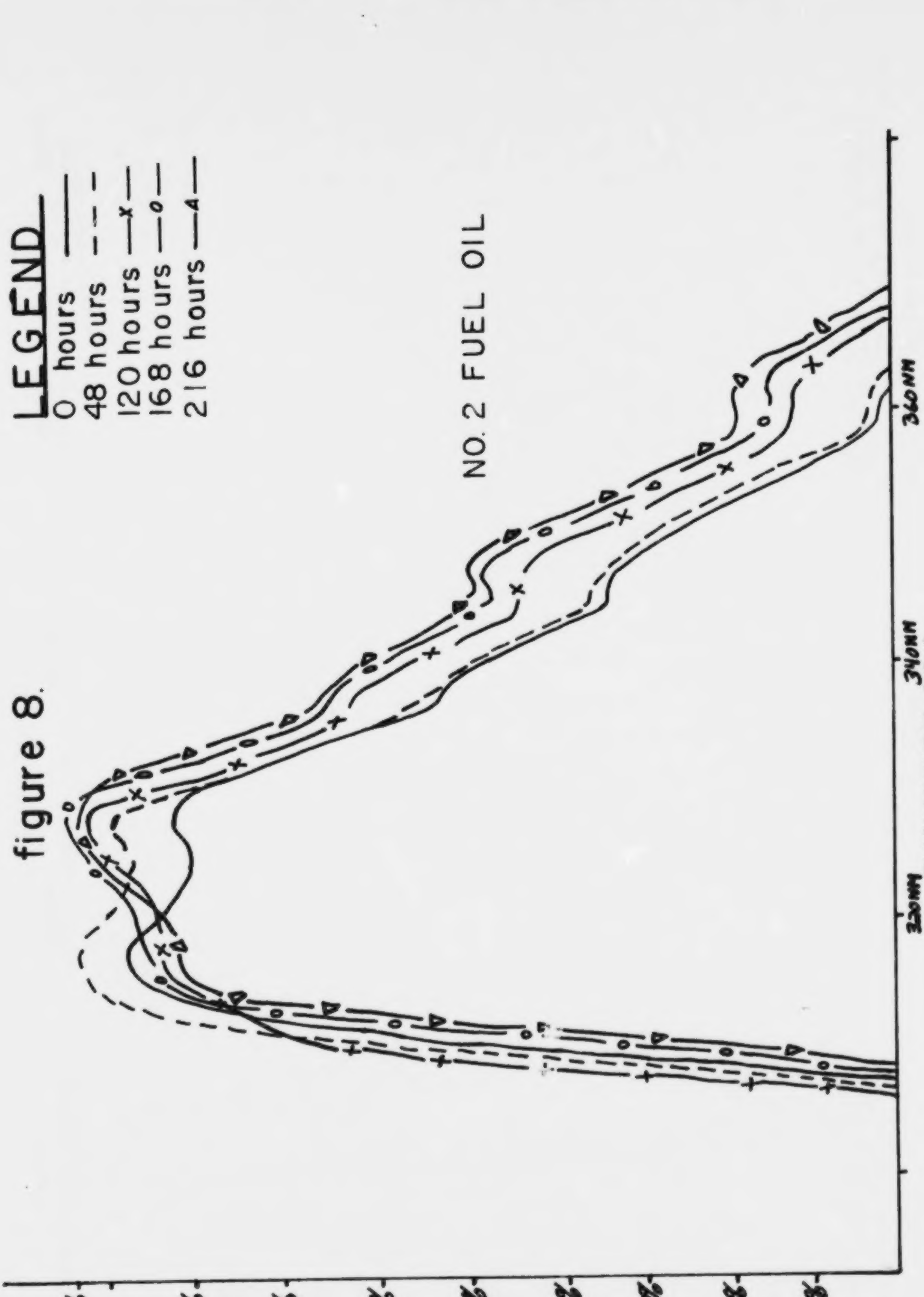

LEGEND
0 hours
48 hours
120 hours
168 hours
216 hours
NO. 2 FUEL OIL
95%
80%
70%
60%
50%
40%
30%
20%
10%
320NM
340NM
360NM
EXCITATION 254NM

figure 9.

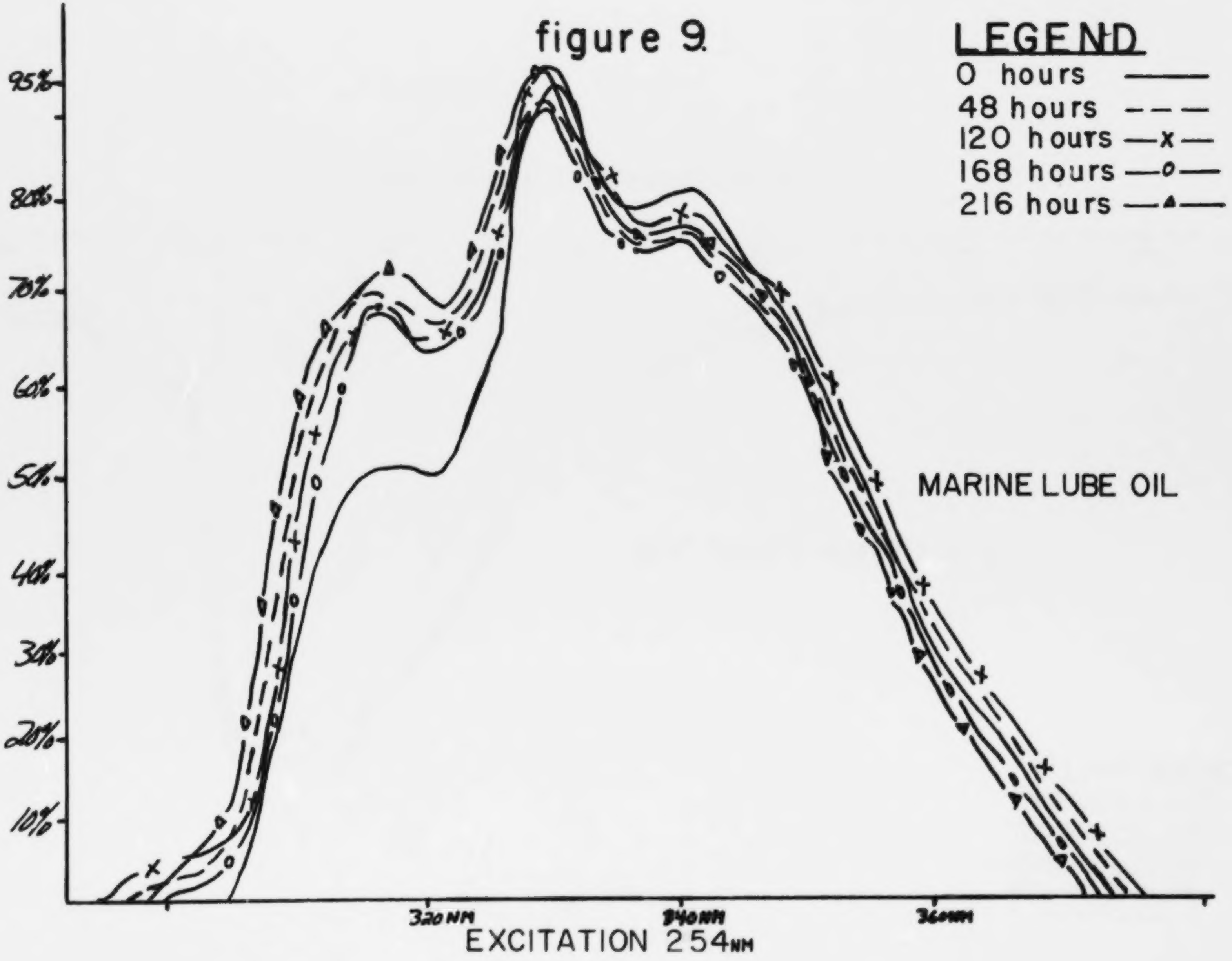
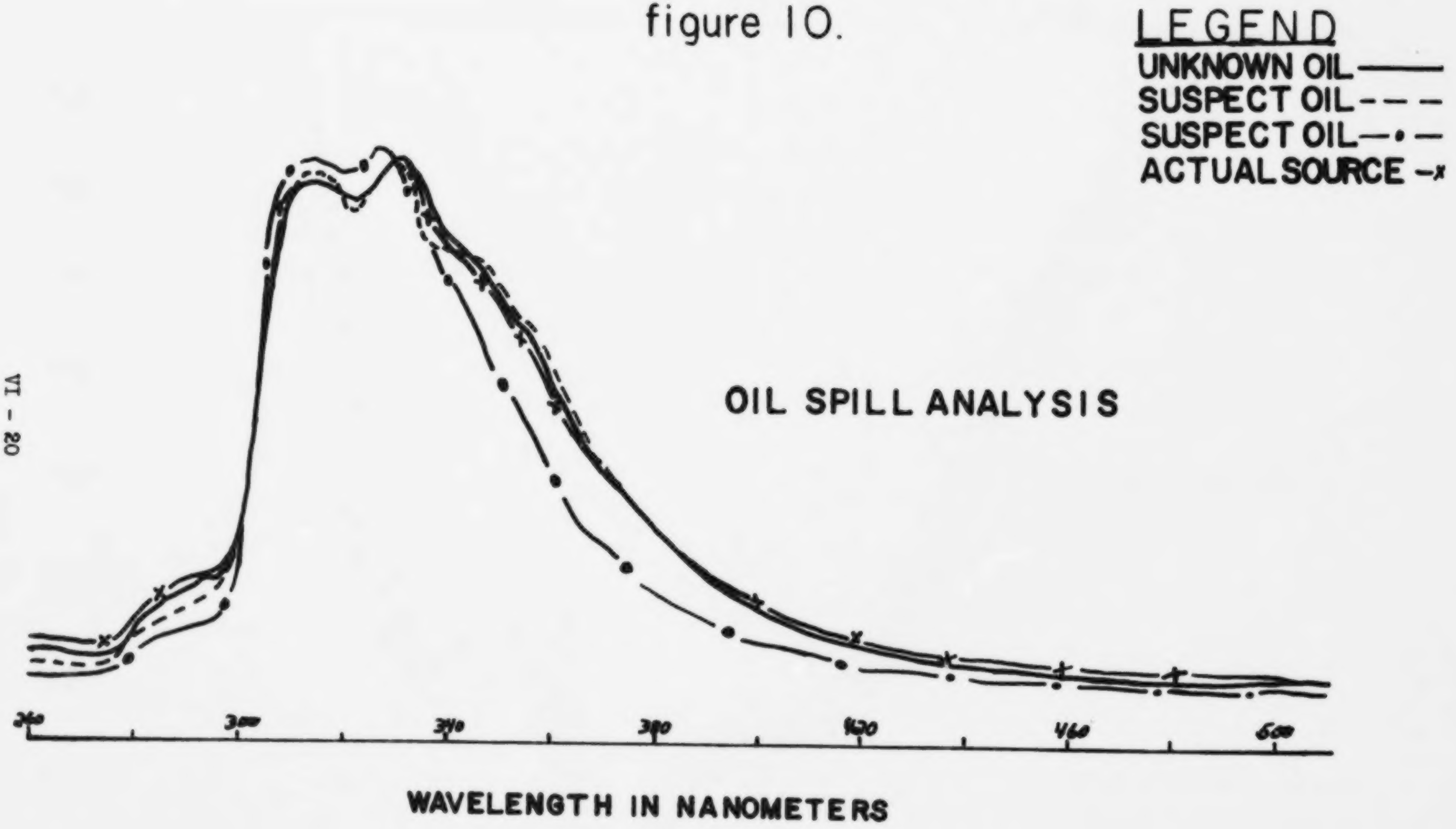

LEGEND
0 hours
48 hours
120 hours
168 hours
216 hours
MARINE LUBE OIL
95%
80%
70%
60%
50%
40%
30%
20%
10%
320NM
340NM
360NM
EXCITATION 254NM

figure 10.



EXCITATION 254NM

July 11, 1973

THE REMOTE DETECTION AND IDENTIFICATION OF SURFACE OIL SPILLS

By

Herbert R. Gram
Spectrogram Corporation

A need has existed for a means to continuously monitor water surfaces for petroleum products and provide an early warning alarm of oil spills or contamination. Of equal importance is the requirement of such a system to type or class identify the detected oil. Such information is meaningful in isolating the source of a spill.

A specific situation required an early warning system to detect a spill or leak of No. 6 fuel oil during barge transfer operations. As many pleasure craft operated in the waters immediately upstream of the transfer point, and are potential sources of general oil pollution, an oil detection system specific to No. 6 fuel oil was desired.

This paper will present the arguments surrounding the initial goals and the conceptual system design of the oil detecting buoy system. The final operational buoy system provides an alert signal when petroleum products are detected on the surface of the monitored waters, and an alarm signal when the oil detected fulfills the fluorimetric spectrochemical criteria for No. 6 fuel oil.

We will further briefly describe the data developed during laboratory studies, the initial breadboard design, and the design of the final buoy system including field performance.

THE REMOTE DETECTION AND IDENTIFICATION OF SURFACE OIL SPILLS

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Presented at Second Conference on Environmental Quality Sensors by the Environmental Protection Agency held at the National Environmental Research Center, Las Vegas, Nevada, on October 10 - 11, 1973.

Spectrogram Corporation
October 10, 1973

The Spectrogram Corporation received an inquiry from a major New England electric power company asking if a dockside oil detection device could be developed that would provide early warning of an oil spill. They explained that most of the power plants have discontinued burning coal and were now burning a petroleum oil classified as Number 6 fuel oil. As the interested power plant is located on a river, the fuel oil is brought to the power plant in large barges of varying length, and transferred to land holding tanks. The transfer rate is typically 600 gallons per minute and deliveries are made both day and night.

Specifically, the power company desired a buoy-type device that could be deployed both fore and aft of the transferring barge. They felt the buoy approach, rather than a fixed dockside device, would provide greater flexibility in allowing for variations in tide, wind, surface currents, barge length, and point of transfer. The buoy could be either battery powered or powered from a dockside console, but no shock hazard should be presented to operating personnel. They desired that the buoys be small, compact and light weight. The system must operate day and night, year round, with minimum maintenance and service, and under the most severe of weather conditions. The choice of detection technique was left to Spectrogram. However, the utility company did again stress simplicity and reliability.

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METHOD SELECTION

The initial step for this program was to examine the literature regarding the various analytical methods by which petroleum oils might be detected. The principal techniques appeared to be: infrared absorption, infrared reflection, visible absorption and reflectance, ultraviolet absorption and reflectance, ultraviolet excited fluorescence, and other possibilities such as aromatic vapor detection, conductivity, etc. We restricted the method selection process by limiting the final design to no moving parts and no contact with the water surface. This included such items as pumps, surface sampling mechanisms, scanning monochromators, optical choppers, etc.

Although a great deal of data was available on infrared techniques for both the detection and the identification of petroleum oils, the approach of IR absorption was ruled out due to the lack of windows in the absorption spectra of water, and, therefore, the need for a mechanical device to sample the water surface. We examined the possibilities of IR reflectance and visible reflectance and concluded very quickly that a number of materials found as floating skim and debris would interfere with the reliable and positive detection of oil. We further determined that the reflectivity was a strong function of oil weathering and solar exposure and additionally noted that the airborne particulate when adsorbed on the surface of an oil slick drastically affected the reflectance characteristics.

Visible and ultraviolet absorption were discarded because of the inability to distinguish between a thick film of a heavy grade oil and any other opaque material or debris floating on the water surface. We were amazed by the amount of natural debris such as leaves, weeds, logs, etc. found on river waters and large clumps of seaweed, etc. found on ocean waters. Needless to say, we did not perform detailed measurements on the above mentioned forms of debris but gathered enough data to demonstrate to our own satisfaction that any method of transmission would be false triggered unless the area under surveillance could be guaranteed free of natural occurring and/or manmade debris.

Methods such as chromatography, surface conductivity, vapor detection, etc. were ruled out due to the complexity of the hardware and the requirement of continuous service such as replenishment of gases, repeated cleaning of optics, and replacement of surface probes.

The most practical and promising approach appeared to be fluorescence or phosphorescence. This approach does not require contact with the water surface, does not require any moving parts, has a minimum number of components, can be made very specific to petroleum oils, and does not require high operating power. Much is available in the literature referencing the field identification of petroleum oils, in particular, as related to geological exploration. Further, optical fluorescence is a tried and proven method as a laboratory analytical tool. Typically, when used in the laboratory, the samples are diluted in solvents such as cyclohexane by factors ranging from 10,000 to 1 to 100,000 to 1.

The sample is then placed in a sample chamber of a commercial spectro-fluorimeter and excited by ultraviolet radiation. Typical excitation wavelengths are in the 200 nanometer to 500 nanometer region with particular emphasis in the region of 260 to 380. The fluorescent radiation emitted typically at 90^0 from the excitation radiation is spectrally dissected to present a display of energy as a function of wavelength over the range of 300 nanometers to greater than 700 nanometers. The high dilutions cited above are required to develop the fine spectral data specific to molecular structure under test. Much data in the form of spectral scans and tabulated results of scans on diluted samples is available in the literature and can be readily generated in the laboratory. As the proposed oil detector would not sample the surface, nor would dilutions in situ be considered, our requirements were for spectral data on undiluted samples of all transportable petroleum products, and further, under a wide variety of environmental conditions. We were not able to uncover much more than a scanty selection of data on undiluted oil samples and were left with no choice but to develop such data in our own laboratory.

Referring now to Figs. 1 and 2, laboratory apparatus was assembled and set up as shown. This allowed the direct excitation of a variety of samples placed directly on the sample stage. To study the effects of temperature on the oil under test, a thermoelectric heat pump was mounted on the sample stage. Prior to the development of special excitation lamps, a standard General Electric germicidal lamp was used to provide excitation energy in the ultraviolet region. Low pressure mercury vapor lamps provide an intense variety of wavelengths in the ultraviolet region as shown in Fig. 3. Through the use of optical filters, specific excitation wavelengths were selected. A series of oil samples of varying type and manufactured source were placed on the sample stage, irradiated and the fluoresced radiation scanned and plotted as signal intensity versus wavelength. These tests were repeated on oils at different temperatures ranging from sub-freezing to 120°F and on samples that had a variety of environmental exposure including sun, rain, and flotation on pools of fresh, brackish and salt water. In all cases, portions of the spectral fingerprint, and, in particular, ratios of selected spectral regions remained substantially constant. It was determined that all oils exhibited overlapping fluorescent signals in the blue region of the visible spectrum when excited by short wavelength ultraviolet radiation. By carefully correlating all the data taken, a compromise wavelength was selected for the purpose of oil detection.

Of equal importance and substantially as a bonus for our efforts, a specific fluorescent peak was found in the red region of the spectrum that was entirely unique to No. 6 fuel oil. We elected to include in future packages two optical detection channels, one for the blue region and one for the red region; the exact operating wavelengths to be selected by the choice of interposing interference filters.

Based upon the encouraging results derived during the laboratory phase, we elected to proceed with a brassboard system that would be capable of field deployment to verify the laboratory findings. It was further decided that an additional optical channel would be added to monitor the ultraviolet reflectance from the water surface. We realized that the data derived from this channel would not be meaningful with respect to the identification or detection of oil but would be meaningful regarding the overall operation of the buoy and act as a water surface monitor. We recognized that the selected detection and identification wavelengths were well within the solar radiation region and some means must be developed to eliminate interference by the sun. Up to the point of detector saturation, all extraneous signals included within the solar radiation band, along with other dockside illumination sources, could be eliminated through the use of a chopped excitation source, AC amplification and phaselock detection. In order that we abide by our initial boundary conditions of no moving parts, a means of electronically modulating the excitation lamp was developed and incorporated within the brassboard design. Prior to the incorporation of a flotation system, the electro-optical buoy head was suspended from the bridge directly over a small river. A section of the river was cordoned off using oil slick booms thus providing a protected and restricted area for in situ evaluation of the overall approach. A small quantity of a variety of oils was spilled on the surface of the river and the signals as generated by the different optical channels were recorded and clearly demonstrated the feasibility of the overall approach. In all cases, the blue channel did provide immediate and instant indication of even mono-molecular layers of petroleum oils on the surface of the water. In each case, the oil was removed from the water surface by the use of commercially available oil clean-up pads. These field tests were repeated several times under different weather conditions both day and night, and in all cases, all oils did trigger the blue channel and the presence of only No. 6 oil triggered the red channel. The field data clearly supported the data generated in the laboratory.

We next reduced the brassboard to a practical prototype package, and deployed these packages on a 24 hour basis in actual operating environments.

PARAMETERS SURROUNDING THE PROTOTYPE DESIGN

The intended application involved only dockside conditions and under normal conditions, the buoys would only be deployed during transfer operations or when a barge was in position for a transfer operation. It was, therefore, decided that cable power from a land based console would prove adequate and, in fact, eliminate the large weight factor of batteries. Further, batteries would require recharging and other maintenance, and unless expensive batteries were employed, the extreme low winter temperature could present additional problems.

To minimize, if not completely eliminate, the potential shock hazard and yet maintain sufficient voltage to provide adequate power with minimum cable current, it was decided that positive and negative 15 Volt DC power would be brought to the buoy. Inverter-type power supplies raised the primary power voltage to the levels required by the multiplying phototubes and the excitation lamp. The balance of the electronics are powered by a secondary regulated supply contained within the buoy.

We proceeded with a series of field tests by deploying one prototype buoy on a river and a second unit in Long Island Sound. The time period for this was ideal with a late summer installation continuing until the following spring. Several engineering problems were encountered such as connector corrosion and packaging material fatigue. However, the units remained operational and responded to test spills of petroleum oils for the entire test period of nine months.

A final operating console was designed to include the various logic circuitry and contact closures necessary to provide a meaningful output. To provide a permanent record of background level signals, analog recorders were employed on the optical channel outputs.

A post engineering effort was devoted to update and finalize the prototype design which has now been installed and is in operation at the power company's oil transfer dock. Fortunately, we can not vouch for actual oil spill detection as no accidental spill has taken place.

FIG. I.

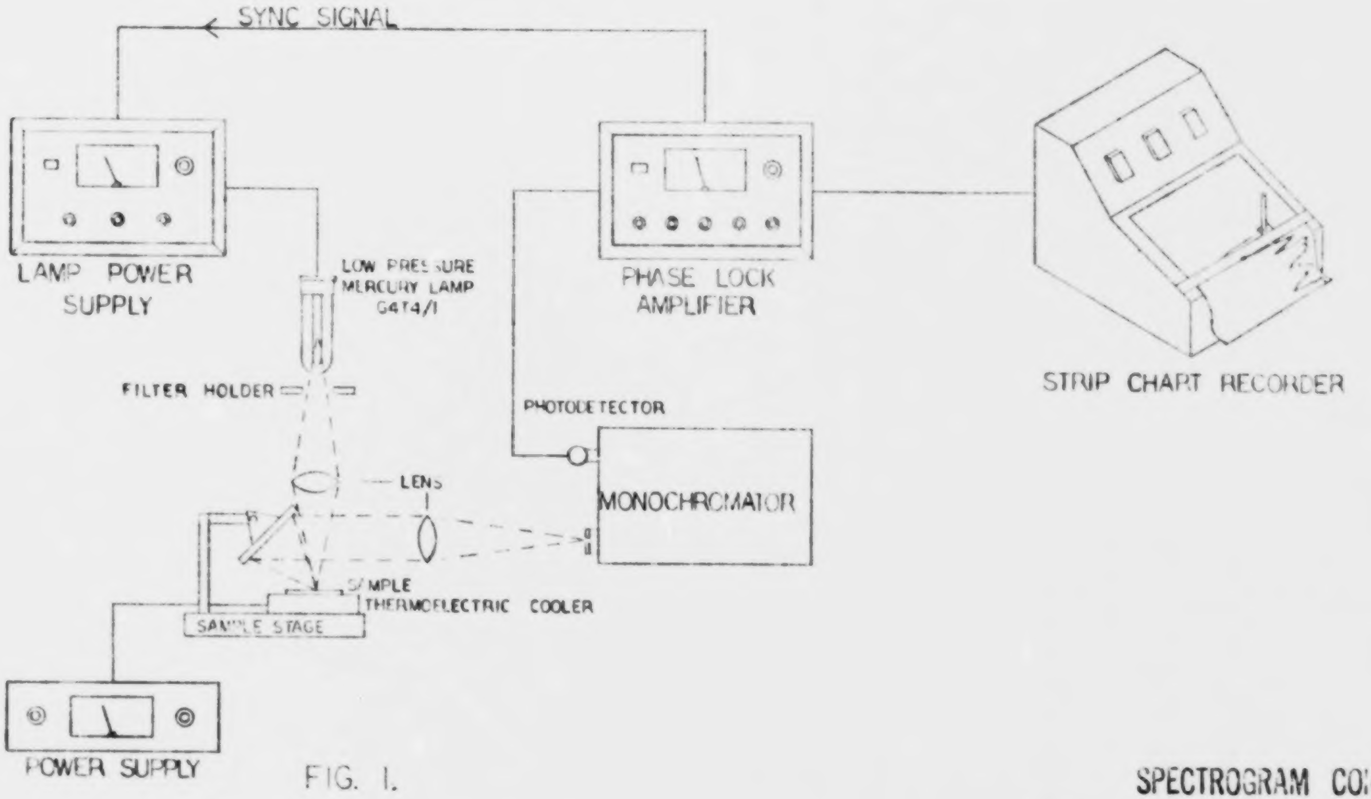

FIG. I.

LABORATORY TEST SET UP
FOR REFLECTION AND
FLUORESCENCE MEASUREMENT

SPECTROGRAM CORPORATION
385 State St.
No. Haven, Conn. 06473

SCALE ———
DATE 6-6-72
APPROVED BY 6-6-72
DRAWN BY

BREAD BOARD "A"

DRAWING NUMBER
P-0201-06[illegible]0

FIG. 2.

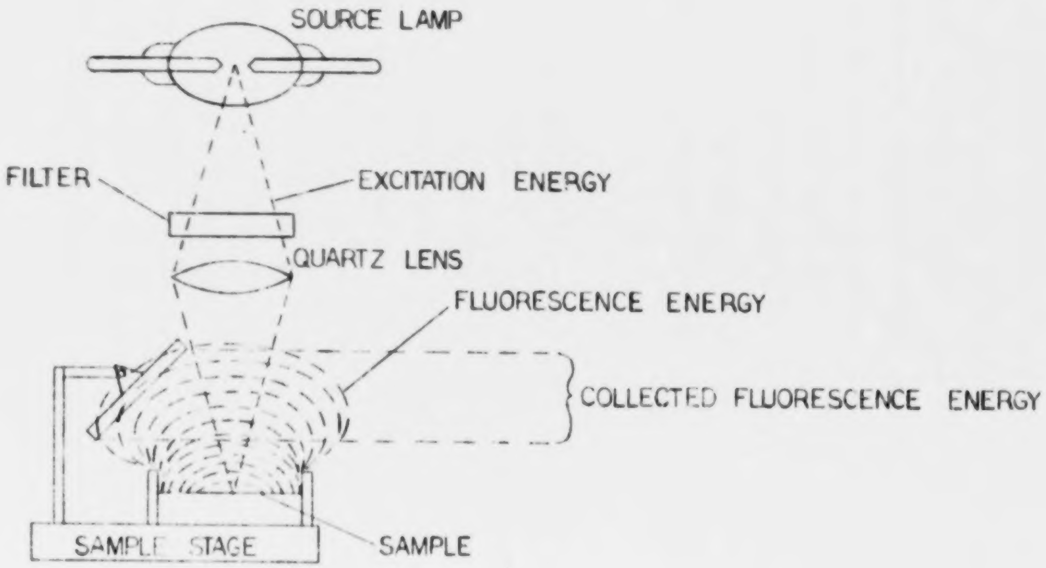

FIG. 2.
DETAIL OF OPTICAL
FLUORESCENCE SYSTEM

SPECTROGRAM CORPORATION
385 State St.
No. Haven, Conn. 06473

SCALE ——
DATE 6-6-72
APPROVED BY J.J. 6-6-72
DRAWN BY

FLUORESCENCE SYSTEM

DRAWING NUMBER [illegible]

ENVIRONMENTAL KEYS FOR OIL AND HAZARDOUS MATERIALS*

by

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St. Louis, Missouri 63166

Aerial remote sensing methods can provide effective and economic means for monitoring real and potential spills of oil and hazardous materials. The advantages of airborne techniques have long been recognized by the military in reconnaissance applications. In particular, large areas can be overflown in a short period of time, and access can be gained into industrial sites where ground truth teams or in situ sensors may be disallowed. With properly selected airborne sensors, data can be collected for detailed analysis of industrial operations, the location of outfalls, the determination of run-off patterns, identification of spill materials, and the surveillance of numerous other environmental problems that would be difficult, if not impossible, to accomplish on the ground in a timely manner. When an episode occurs, an aircraft can be dispatched to the scene for acquisition of data for enforcement purposes. Often times, due to time and location constraints, aerial surveillance is the only means to assess the extent of damage. These advantages are made possible by the aircraft, however, the viability of remote sensing is due to the data collection systems.

The need for sensors capable of directly detecting the many varied pollutants has caused a great deal of emphasis in developing sensor technology for data collection. However, field use of sensors requires exploitation of sensing technology which includes data collection, data reduction and analysis, and finally information extraction. Once sensor systems are developed, tested, and deployed, the most important part of remote sensing is in the extraction of information from that data collected. This step places man as part of the system to make decisions. The sensor design engineer often ignores the associated system requirements. Typically, new sensors are tested under controlled or at least known conditions so that that information extraction can be treated as a test result. This paper addresses the very important requirement for imagery interpretation keys used by interpreters to extract information from data collected with imaging sensors. Examples of aerial imagery are discussed to emphasize the value of such keys.

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* This work was sponsored in part by the U.S. Environmental Protection Agency under Contract Numbers 68-10-0140 and 68-01-0178.

To realize the full potential of remote sensing, the complete inventory of existing sensors and newly developed sensors may have to be exploited. Because the types of industries and associated pollutants are so varied, the problem of data collection and interpretation can be quite complex. This can be explained best by first looking at a simple explanation of the physics of remote sensing.

Since the sensor is airborne, its only mechanism for detecting the pollutant is the collection and recording of electromagnetic waves scattered or emitted from that material. These EM waves carry information about the scattering material which discriminates it from the surrounding material. This process is easily recognized when the sensor is a camera and the data is displayed as a photograph. The unskilled interpreter can look at an aerial photograph and recognize rivers and lakes and even oil refinery storage tanks (if he knows he is looking at an oil refinery). How does this novitiate arrive at his conclusions? He simply looks at the geometrical shapes defined by the recorded contracts, compares these shapes with his mental storehouse of knowledge, and makes his decision. He really doesn't have to understand any physics or chemistry.

To elucidate further, Figure 1 is presented as an example. The factory displayed in the aerial photograph is a titanium plant adjacent to a major river. The whole manufacturing facility is shown, including the several outfalls. The unskilled interpreter probably would say little about the factory except that it looks complicated and appears to be dumping something into the river. The skilled interpreter, using direct analysis could offer an abundance of information on conditions of the facilities and other apparent information, but he too could not identify the content of the outfalls as hazardous or non-hazardous. Both interpreters have evaluated the geometries and contrasts to arrive at conclusions. This is the essence of "direct analysis".

More information could be gleaned from Figure 1 if the interpreter had an imagery interpretation key for titanium plants designed for environmental use. Such a tool would describe the entire plant operation with many photographic views of each type of facility. A chemical description of the operation also would be given so that products and wastes would have their origins and destinations identified. With a key the interpreter may be able to determine that at location (A) the outfall contains ore-gangue; cooling basin overflow river water is being dumped at (B); at (C), (D), (E) and (G), process water with various pollutants is discharged; and at

(F) the discharge contains titanium dioxide, ferrous sulphate, and sulfuric acid. (This information was gained by ground truth collected during an EPA sponsored study.) To arrive at such conclusions the interpreter would employ "deductive analysis" since no direct data is available. Deductive analysis requires tracing the outfall content back to its source.

By using other sensors, additional data can be collected to detect pollution. For example, thermal imagery is the result of detection of radiation in the infrared (IR) spectrum. The IR sensor provides data outside the spectral range of photographic cameras. Therefore, the sensor complements cameras by supplying added spectral information capability. An example of thermal infrared detection of pollution being discharged from a steel mill is shown in Figure 2. Hot drainage is observed in the ditches leading from the plant to the adjacent river. Not only is the thermal pollution evident, but its presence and apparent source suggests that it may be a hazardous material. If such data were collected concurrently with photographic data and a properly constructed imagery interpretation key were available, then the material emitting heat could possibly be identified.

By detecting discrete spectral bands in the visible and infrared spectrum, a very crude spectrographic analysis can be accomplished. Figure 3 shows five channels of imagery from a multispectral scanner. The scene is a portion of a river basin downstream from industrial activity. Comparison of contrasts with the knowledge of spectral signatures of materials reveals evidence of residual industrial pollution in the river basin. However, without a special interpretation key providing guidance in making a comparative analysis, such information could not be obtained. Such a key requires corroborative ground truth in its formulation to establish confidence in information extraction. The illustration demonstrates that the spectral characteristics of an area can be detected for evaluation and interpretation by direct analysis when the proper key is available.

The foregoing discussion points out the strong potential value of aerial remote sensing for the detection of oil and hazardous materials. Although sensors can collect the necessary data, the actual detection is not accomplished until that data is analyzed and interpreted. This task is not a simple one. Types of pollution are quite varied and can originate in many different kinds of industries ranging from uncomplicated municipal sewage treatment plants to complex chemical plants and oil refineries. Furthermore, data collected with different types of sensors requires different rules for analysis (as illustrated by Figures 1 through 3). Therefore, an EPA interpreter is confronted with a nearly impossible task unless he has "guidebooks for analysis" to aid in his job. These guidebooks, or keys, are actually essential to the field use of the environmental remote sensing system.

The design of an interpretation key for environmental applications must emphasize the need to detect conditions that create pollution. An approach to such design would be to describe the manufacturing processes for the selected industry so that all products, by-products, and waste materials can be traced from their origins to their final disposition. Such information would have to be presented through processing diagrams (i.e., flow charts), photographs of facilities from several aspect angles, and verbal descriptions of facilities and events in a language needed for recognition by an interpreter. If special sensors are used, then interpretation information regarding methods of analyzing the data collected by such sensors is required. A key containing such information would permit identification of spill sources within the confines of the industry premises. Furthermore, deductive analysis of outfalls would be more reliable when direct analysis isn't possible.

McDonnell Aircraft Company, under contract to the EPA, used the approach described above to develop an Aerial Spill Detection Key for Petroleum Refineries. The selection of this industry allowed a reasonable demonstration of the approach since the refinery processes are quite complex in their photographic rendition. Figure 4 shows a flow diagram of a typical petroleum refinery similar to that which may be found in a military key. Features that are not shown are the origin, flow, and disposition of waste materials. Process descriptions, simplified flow diagrams, and aerial photographs for each phase of the operation depicted in Figure 4 with the additional environmental data were included to provide the interpreter with the required information.

The aerial surveillance system used to collect the data for the development of the key consisted of a cartographic camera, a multiband camera array, and low performance commercial aircraft. These are shown in Figure 5. The cartographic camera was chosen to provide baseline imagery for standard photogrammetric (cartographic when needed) and interpretation analysis. The multiband cameras were used as the special sensor to collect spectral information. This was accomplished by judiciously selecting photographic film and filter combinations to record only that light which would emphasize the spectral reflectance of petroleum waste material or spilled oil. Comparison of the simultaneously obtained photographs from the four cameras of the array provided a crude spectral analysis. Figure 6 shows the spectral sensitivity curves of the black and white films used. Color film was also used to obtain color discrimination for cueing of suspect pollution areas. The direct analysis techniques for the multiband imagery provided in the resulting key are correlated with the analysis of the baseline imagery.

To illustrate features of the key that are essential to effective imagery analysis, several sample figures have been selected for discussion. Figure 7 shows two views of a lubricating oil refinery area. The oblique view is used to orient the analyst (trained or untrained). The specific processing areas are identified as deasphalting at A, solvent extraction at B, dewaxing at C, and clay treating at D. Each area has unique features that can be readily identified. The vertical view of the same scene, shown in Figure 7b, permits detailed analysis of the area. Features such as storage tank conditions and revetment inadequacies can be detected and could signal potential spill sources. Multiband imagery of the area (not shown) could reveal spilled material.

A particular processing area of the lubricating oil refining is described in detail by using a simplified flow diagram (Figure 8). This figure describes the solvent extraction process and provides a functional background for recognizing facilities. It also identifies those materials that could be spilled at this location. Such a diagram accompanied by textual information precedes representative imagery in the key. A view that allows detailed direct analysis is the stereo pair. Figure 9 is an example showing the solvent extraction process where settling tanks and furnaces are located at positions A and B respectively. This type of display presents a three dimensional view of objects when used with any stereo optical device. Sizing and volumetric data can be obtained in addition to terrain features that may establish the run-off patterns.

The products of the petroleum refinery are stored in tanks of many shapes and sizes. The storage area may occupy up to 75 percent of the refinery area. It is in this area that the potential for spills is most prevalent. Normally, the analyst would be concerned with recognizing the types of storage tanks and, by inference, the stored material; the condition of storage tanks; and the condition and adequacy of the revetments. It is important to note that various industries have different practices in storing material so that the interpretive inferences for petroleum refinery storage would be inapplicable to other industries.

The potential pollution source in a storage tank area shown in Figure 10 is typical of data needed in an environmental key. The leaking tank in the ground view is readily observed at position (A) in the stereo pair. Of course, the analyst would use a stereo viewer to provide an enlarged three dimensional image to perform his task.

The type of storage tank when correlated with location and related features often provides a reliable clue to the identity of the tank contents. However, shortage of space or increased demand for specific products may dictate that tanks be used for products other than those for which the tank was designed. Ideally, low volatile crude oil is stored in fixed roof cylindrical tanks. To reduce evaporation, the more volatile products are best stored in breather tanks, floating roof, spherical, or spheroidal tanks. The tanks designed primarily for storing gases under pressure are the butane, spherical, and spheroidal tanks.

The oblique photograph shown in Figure 11 shows a typical mix of tanks commonly seen in a refinery. Examples include a group of fixed roof cylindrical tanks at (A), spherical tanks at (B), vertical butane at (C), horizontal butane at (D), and floating roof cylindrical tanks at (E).

The multiband imagery shown in Figure 12 is the final example of imagery used in the petroleum refinery key. These simultaneous photographs show a waste area that is typical of refineries. Often times such areas are located near the water treatment ponds that lead to outfalls. These parts of the refinery compound can be suspect as pollution sources. However, the goal of the industry is to properly treat, confine, and eventually safely remove the waste material. The numbers appearing beneath each picture indicate the film and filter combination (the four digit number specifying film type and the two digit number specifying the filter). The information provided in the key tells the interpreter how to make contrast comparisons to perform a crude spectral analysis for materials identification.

The Aerial Spill Detection Key that was developed was used to evaluate imagery of several refineries taken with the same aerial camera systems. With some time spent in familiarization, the interpreters found the key to be invaluable. Clearly, the benefits of the aerial technique were demonstrated during the aerial surveillance program. Ground truth teams collected correlative data which confirmed the effectiveness of the imagery interpretation. Also this coordinated correlative study emphasized the tremendous time advantage and data collection capability inherent in the airborne remote sensing method. At the very least, such techniques complement ground surveillance by locating suspicious areas so that field investigation teams operating on the ground need not spend time observing "clean" areas.

The importance of environmental keys has been demonstrated. The successful implementation of aerial remote sensing for detecting and identifying pollution sources through field investigations necessitates effective information extraction methods and tools.

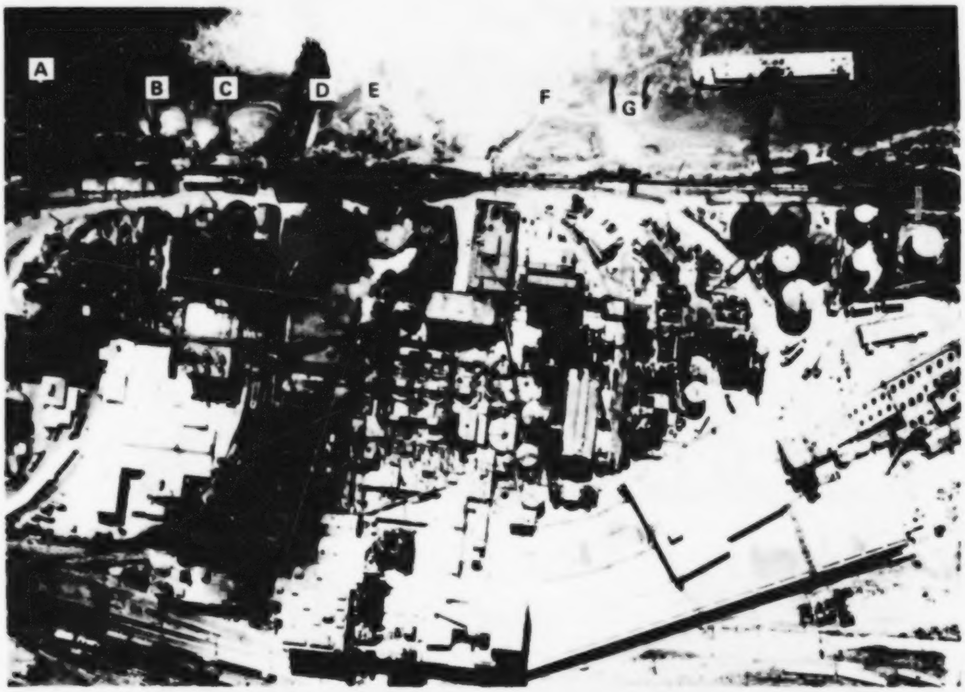


FIGURE 1 TITANIUM PLANT SHOWING OUTFALLS

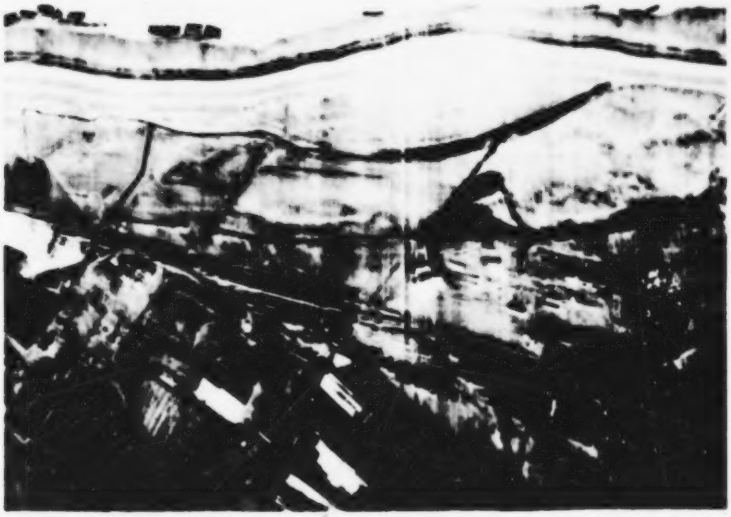
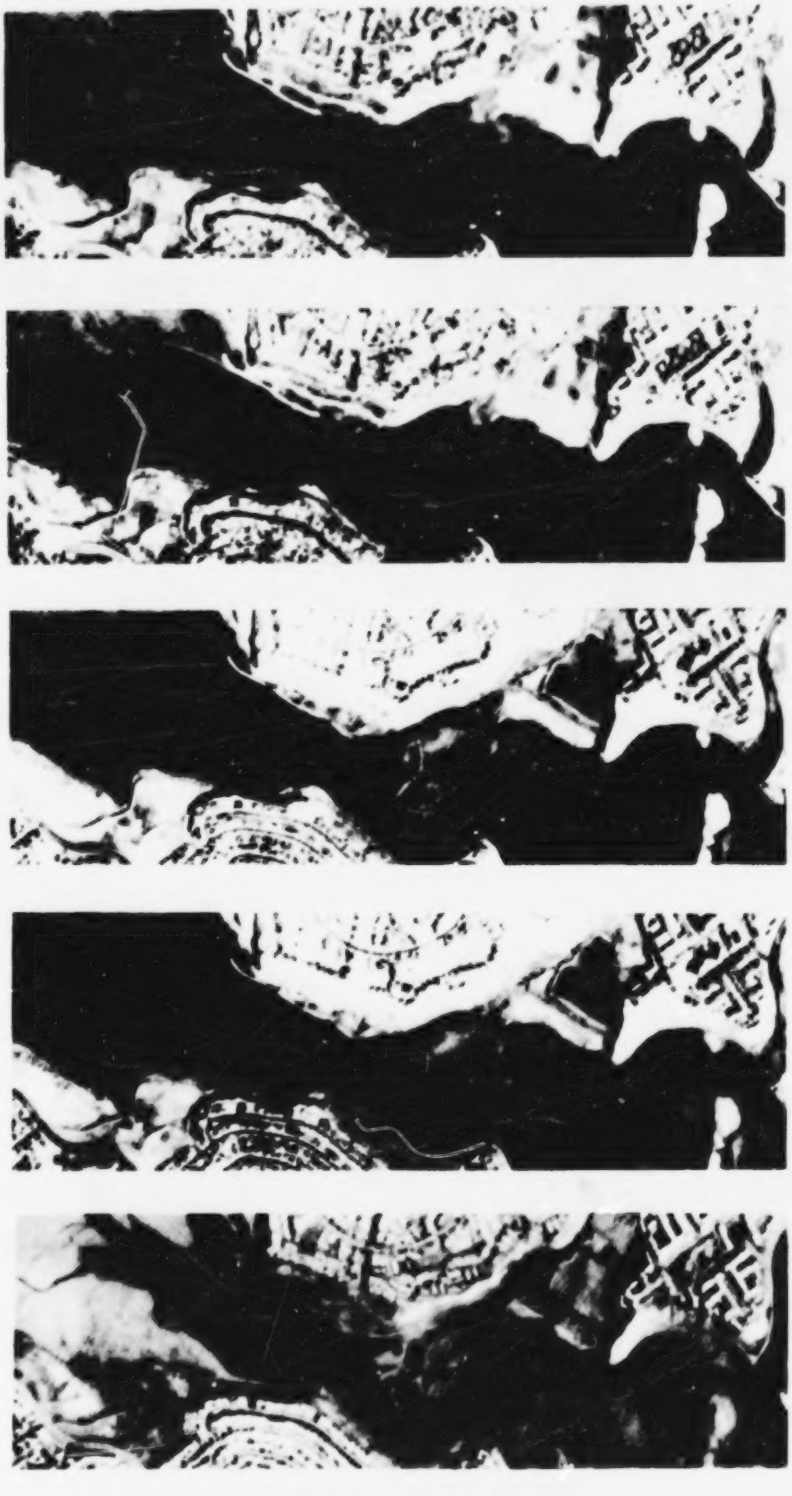


FIGURE 2 THERMAL INFRARED IMAGE OF STEEL MILL AND INDUSTRIAL WASTES



Band 1
0.5 - 0.6 µm

Band 2
0.6 - 0.7 µm

Band 3
0.7 - 0.8 µm

Band 4
0.8 - 1.1 µm

Band 5
10.4 - 12.6 µm

FIGURE 3 MULTISPECTRAL SCANNER IMAGERY OF A RIVER BASIN

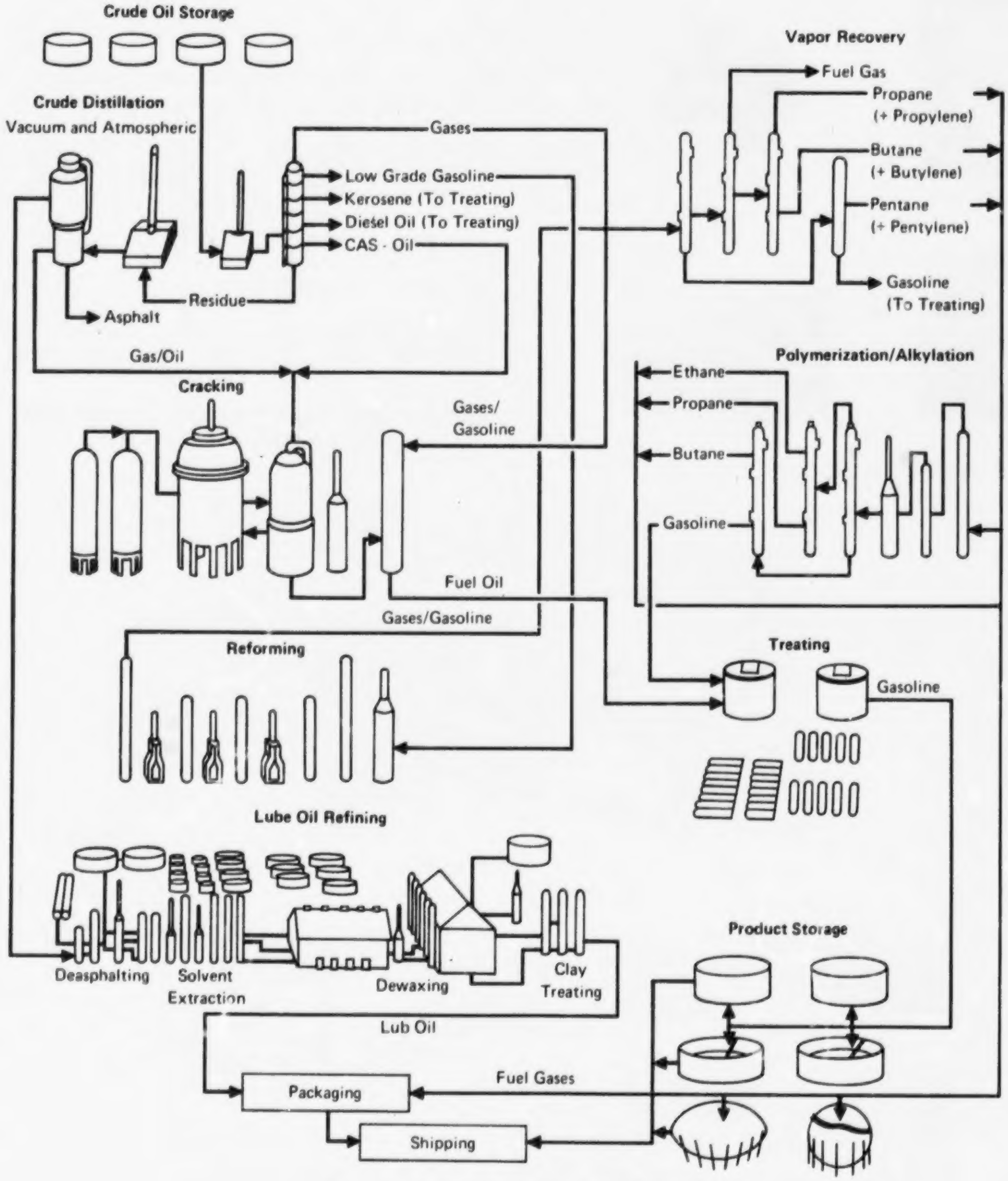
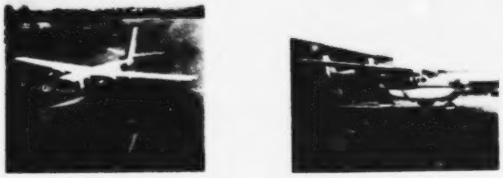


FIGURE 4 FLOW OF TYPICAL REFINERY

Zeiss RMK 1523 Camera

Hasselblad
Camera Array



Aero Commander

Cessna 336

FIGURE 5 AERIAL SURVEILLANCE SYSTEM

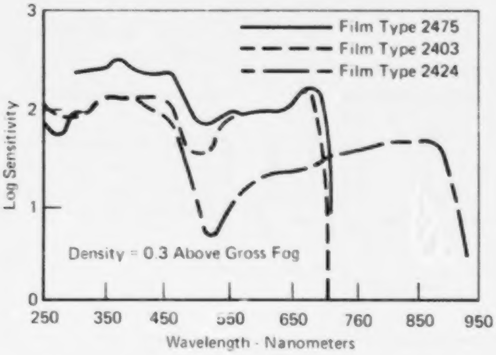


FIGURE 6 SPECTRAL SENSITIVITY CURVES FOR PHOTOGRAPHIC FILMS

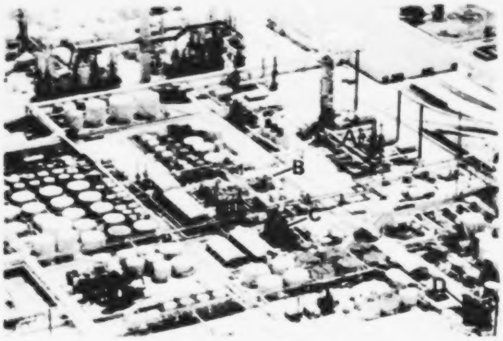


FIGURE 7a LUBRICATING OIL REFINING - OBLIQUE VIEW

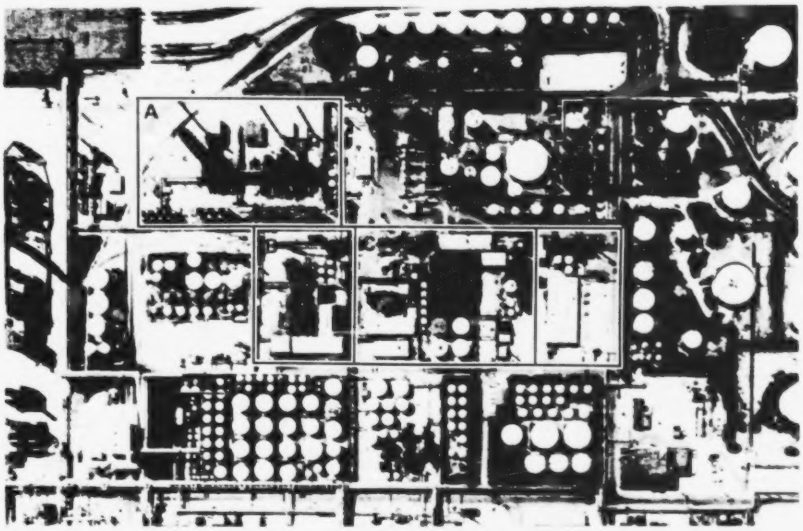


FIGURE 7b LUBRICATING OIL REFINING - VERTICAL VIEW

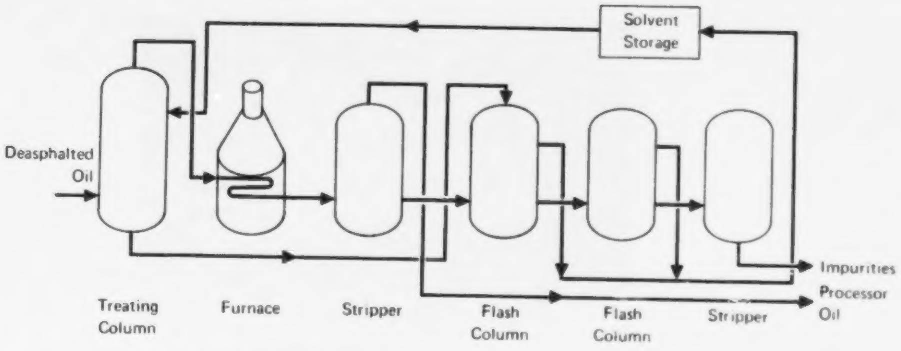


FIGURE 8 SIMPLIFIED FLOW OF SOLVENT EXTRACTION

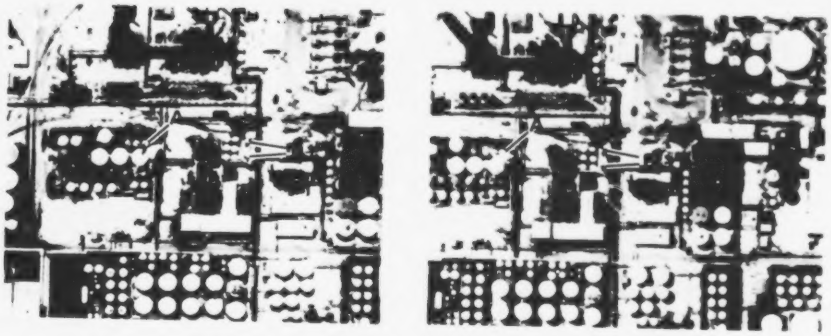


FIGURE 9 LUBRICATING OIL REFINING, SOLVENT EXTRACTION

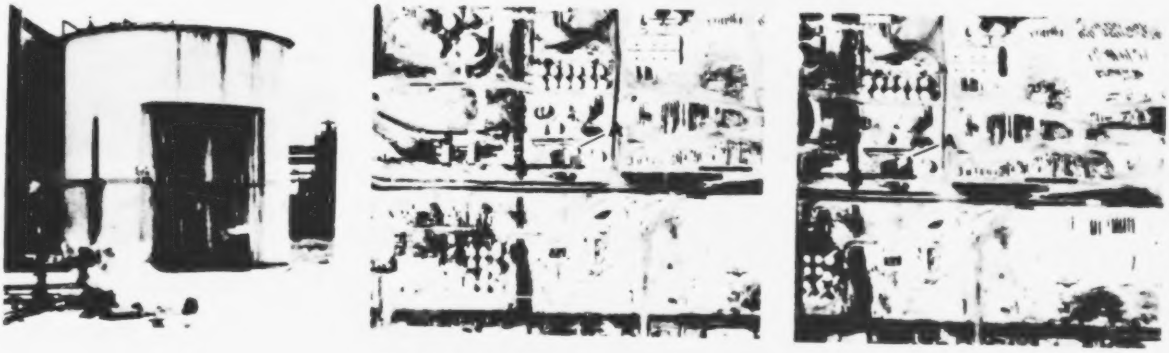


FIGURE 10 STORAGE, LEAKING TANKS

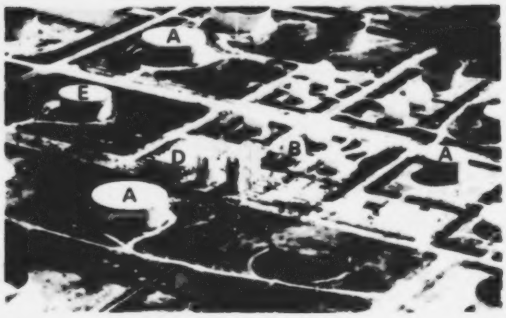
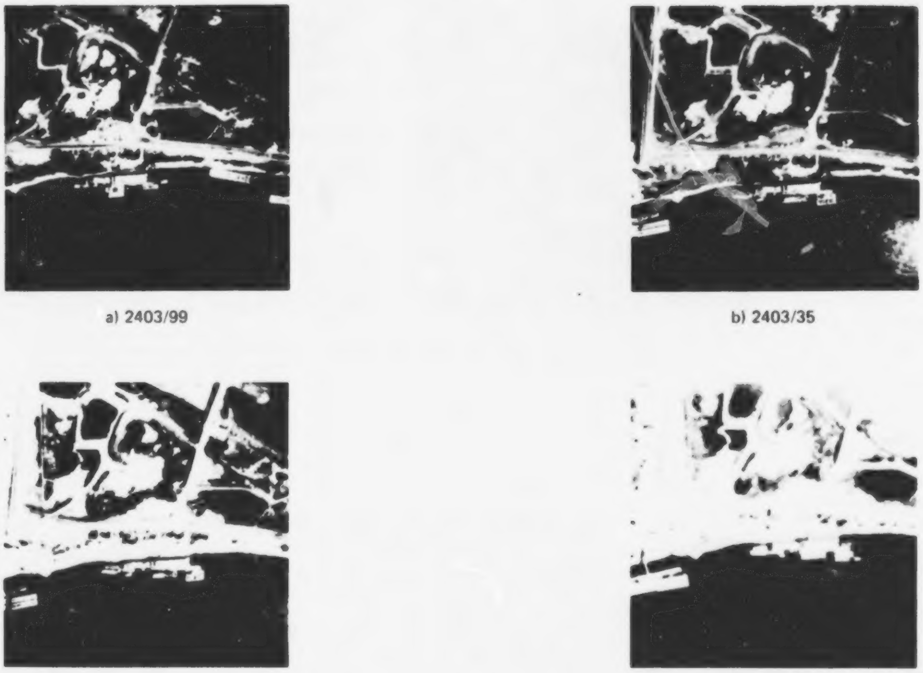


FIGURE 11 STORAGE TANKS



a) 2403/99

b) 2403/35

c) 2424/99

d) 2424/35

FIGURE 12 PETROLEUM WASTE AREA

VIDEO DETECTION OF OIL SPILLS*

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Ames Research Center, NASA, Moffett Field, Calif. 94035

and

Gerald F. Woolever, LCDR
USCG – Headquarters, Washington, D. C.

ABSTRACT

Three airborne television systems are being developed to evaluate techniques for oil-spill surveillance. These include a conventional TV camera, two cameras operating in a subtractive mode, and a field-sequential camera. False-color enhancement and wavelength and polarization filtering are also employed. The first of a series of flight tests indicates that an appropriately filtered conventional TV camera is a relatively inexpensive method of improving contrast between oil and water. False-color enhancement improves the contrast, but the problem of sun glint now limits the application to overcast days. Future effort will be aimed toward a one-camera system. Solving the sun-glint problem and developing the field-sequential camera into an operable system offers potential for color "flaging" oil on water.

INTRODUCTION

Airborne surveillance of oil spills offers the advantages of large-area coverage, covert detection, and quick response to spill accidents. Unfortunately, the human eye is not a particularly good detector of thin films of oil on water[1,2] for reasons having to do with the spectral response of the eye,[3] the absorptance/reflectance characteristics of oil and water,[4] and the polarization characteristics of skylight.[5] Due to these factors, an unaided observer viewing from an aircraft often sees little contrast between oil and water. Various systems are currently being evaluated for their ability to provide a better means of detection. Among these are the video systems discussed in this paper.

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*This work was performed under Coast Guard MIPR Z-70099-2-23146. The opinions or assertions contained here are those of the writers and are not to be construed as official or reflecting the views of the Commandant of the Coast Guard.

Video systems have potential for displaying a greater contrast between oil and water than the unaided eye would observe. These systems are real-time and can operate in the near-ultraviolet and optical-infrared portions of the spectrum. These systems are amenable to polarization techniques; they can produce a real-time, false-color display of a low contrast scene, and they have potential for night surveillance. Prior studies indicate improved contrast between oil and water when sensing in the near-UV[6-12] and optical-infrared[6,9,10,13] portions of the spectrum, when viewing through a polarizer oriented to transmit the horizontal polarization component,[2,5] and when subtracting signals acquired through two orthogonally oriented polarimeters.[6]

Ames Research Center is developing and/or flight testing basic video systems and techniques for oil spill surveillance by the U.S. Coast Guard. Two systems have been flight tested, and a third is being developed. This paper describes the systems, techniques, and flight results.

SYSTEMS AND TECHNIQUES

Systems

The three basic systems being developed for flight test are illustrated schematically in Fig. 1, and their components are specified in Table I.

System 1 is composed of a conventional TV camera and a black/white monitor (Fig. 2). The camera has a silicon-diode-array image tube, as do all the cameras in this study, and a lens with an automatically controlled iris. As shown in Fig. 1, the camera output was also processed through system 2 to display a false-colored image.

System 2 is composed of two conventional TV cameras (Fig. 3) viewing the same scene through different filters, a video processor designed to subtract one image from another and false-color the resultant image, and a color monitor (Fig. 4). The processor will also accept a single video signal and false-color it.

System 3 consists of a high signal/noise field-sequential camera, a special processor to enhance the information content of the video signal, and a color monitor modified for field-sequential operation. A field-sequential camera has a single-image tube with a spinning filter wheel in front. The filter wheel may contain up to three filters (polarization and/or wavelength filters). In operation, the video signal through each filter actuates a color gun in a monitor. Thus, the color displayed on the monitor corresponds to wavelength or polarization characteristics of the scene being viewed.

The TV cameras were mounted in the nose of a Cessna 402 (Figs. 5 and 6), downward viewing at 45°. The cylindrical tubes in these figures are air-sampling ducts for another project. All other equipment was mounted in racks in the aircraft cabin (as shown in Fig. 4).

Techniques

The techniques being evaluated and the rationale behind them are:

Technique 1 – Wavelength and Polarization Filtering

This technique enhances the contrast between oil and water by viewing the target scene through selected wavelength and polarization filters. The rationale for selective filtering is that it allows surface features of water to be emphasized rather than subsurface features. In the near-UV and optical-infrared portions of the spectrum, water absorbs much of the light backscattered beneath the surface, causing the contrast between oil and water to be determined primarily by the surface reflectances of oil and water. Oil has a higher reflectance than water and thus appears brighter. The silicon diode array tubes used in this study are useful because of their broad spectra response. With glass optics, measurements were made over spectral bands from 370 to 1000 nm.

For polarization filtering, Ref. 2 reported high contrast by measuring only the horizontal component of polarization. This high contrast is attributable to the high reflectance of liquid surfaces for this component and the difference in reflectance between oil and water. Figure 7 illustrates the reflectance characteristics of oil and water for the two principal polarization components.

Technique 2 – Subtraction of Orthogonal Polarization Components

This technique utilizes two bore-sighted cameras, each viewing through a polarizer oriented 90° to the other. In real time, one image is subtracted from the other and the resultant image is displayed on a monitor. This technique was previously reported in Ref. 6, where measurements were made with radiometers. By means of this technique, redundant information (unpolarized radiation) is canceled and the contrast between oil and water due to polarization differences is enhanced. A second possible improvement in contrast is based on the fact that skylight polarization varies with position in the sky. An airborne observer viewing an oil slick sees different portions of sky reflected by oil and water. Thus he sees the polarization characteristics of two different portions of sky modified by the reflectance characteristics of oil and water. In the present study, this technique was evaluated with system 2.

Technique 3 – False-Color Enhancement

The objective of this technique is to enhance the contrast between oil and water by causing each to appear in a distinct vivid color. To accomplish this, a video signal normally corresponding to various gray levels is automatically "sliced" into a number of amplitude ranges. A color is assigned to each range, and the colored image is displayed on a TV monitor. All ranges need not be colored or displayed. If oil is brighter or darker than the surrounding water, it will appear as a different color. This technique has been used for several years in the laboratory (e.g., Ref. 14) to enhance subtle features in photographic imagery, but no prior real-time application is known.

Technique 4 – Field-Sequential Processing

This technique is designed to produce high contrast between oil and water again by using color to enhance the visual display. A specially designed, field-sequential camera is used, and the video signals from up to three filters individually drive the color guns on a monitor. When a disparity between oil and water exists in any one of these filter regions, the corresponding color gun will be affected and oil will be displayed in a color different from the surrounding water. To accentuate color differences, the system uses an automatic gain control to keep the maximum video signal at a preset level, and a threshold detector to drive any one color gun to maximum output when its video signal exceeds preset amplitude levels.

RESULTS AND CONCLUSIONS

The first in a series of flight tests of various video systems and techniques was conducted over a period of several weeks and under a variety of weather conditions in the vicinity of the oil platforms in the Santa Barbara channel. The results and conclusions are as follows:

System 1 – Conventional TV Camera / Balck/White or False-Color

The result of most immediate importance is that significantly enhanced detection of oil films, relative to the eye, was achieved with an appropriately filtered, conventional TV camera and a black/white monitor. The camera contained a silicon-diode-array image tube and standard glass optics. It was filtered with a polarizer oriented with its principal axis in the horizontal direction and a Corning 7-54 filter, which blocks out the visible and transmits the near-UV and optical-infrared portions of the spectrum. Examples of the imagery are shown in Fig. 8; the oil appears as a bright white against a dark water background. The video presentation was often used to direct the pilot over a slick area when it could not be seen visually. Measurements were made in various wavelength regions, with and without polarizers. Best contrast was consistently obtained with a polarizer oriented to transmit the horizontal component and a Corning 7-54 filter.

Unknowns presently associated with the single-camera system are the thicknesses and types of oil to which it will respond. There were instances (as illustrated in the last two photographs of Fig. 8) where a portion of a slick appeared dark. This was probably associated with a thick portion of the slick. There were instances over other geographical areas where what appeared to be "thin" slicks did not show up well at all. These occurrences were probably associated with both thickness and type of oil. (Evaluation of these parameters will be conducted by the authors in the near future.)

The video signals were false-colored in real time. This technique provided an easy means for detecting anomalies on a water surface; for instance, the system was operated so that natural water appeared as yellow and oil appeared as blue; however, sun glint was a problem on clear days. Sun glint caused a spike in the video signal with the result that the photograph contained a series of concentric colored circles (Fig. 9) emanating from the specular direction. Under overcast skies, this problem did not exist. Work is underway to investigate techniques for filtering the solar spike out of the video signal.

System 2 – Two-Camera System / Black/White or False-Color

The two-camera system was operated with polarizers, rotated 90° to each other, in a subtractive mode. Oil slicks were easily detected by this technique, but generally no more easily than with a one-camera system – with one exception: the subtractive technique minimized the effects of solar spikes in video signals when the sun glint was reflected directly into the TV cameras. Generally, however, the necessity of aligning two cameras appears to outweigh the advantages of this technique. The false-color technique also worked well with this system.

System 3 – Field Sequential

The field-sequential system was not tested because its design and manufacture were not yet complete.

General

The results described here are those from the first of a series of tests to be conducted. It cannot be stated which system is optimum because of the limited testing at the present time. However, the authors believe that future efforts should be aimed toward a one-camera system. The one-camera conventional system described here offers a relatively inexpensive method of improving contrast over oil spills. Solving the sun-glint problem associated with false-color and developing the field-sequential system offer potentials for further system improvement.

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TABLE I. – SYSTEM COMPONENTS

Component	Description	Comments
Filter #1	Corning 7-54	Transmits below 420 nm and above 670 nm
Filter #2	Polaroid Polarizer HN 32	
Filter #3	Kodak 89B	Transmits above 680 nm
Filter #4	Optics Technology 166	Transmits from 410 to 600 nm
Filter #5	Optics Technology 787	Transmits from 390 to 560 nm
Filter #6	Optics Technology IR absorbing glass	Absorbs above 700 nm
TV Camera #1	Sanyo Model VCS-3000	2/3" silicon-diode array tube; autocontrolled iris
TV Camera #2A	Sierra Scientific Minicon	1" silicon-diode array tube; manual or remote controlled iris
TV Camera #2B	Sierra Scientific Minicon	1" silicon-diode array tube; manual or remote controlled iris
TV Camera #3	Zia Associates Inc. Field-Sequential	1" silicon-diode array tube; S/N > 200:1; auto-controlled iris; auto-shading correction
Processor #1	International Imaging Systems Differential Video Processor Model 4490	Capable of subtracting one video signal from another, false-coloring video signals, and processing the signals so they may be presented in combinations of false color and black/white
Processor #2	Zia Associates Inc. Field-Sequential Processor	Capable of eliminating unwanted background portion of video signal and amplifying information content. Provides selection of colors in which signal may be presented. Provides threshold level for producing saturated colors for signals above a selected value.
Monitor #1	Tektronix Model 632	Black/white
Monitor #2	Tektronix Model 654	Color
Monitor #3	Sony Model PVM 1200	Color

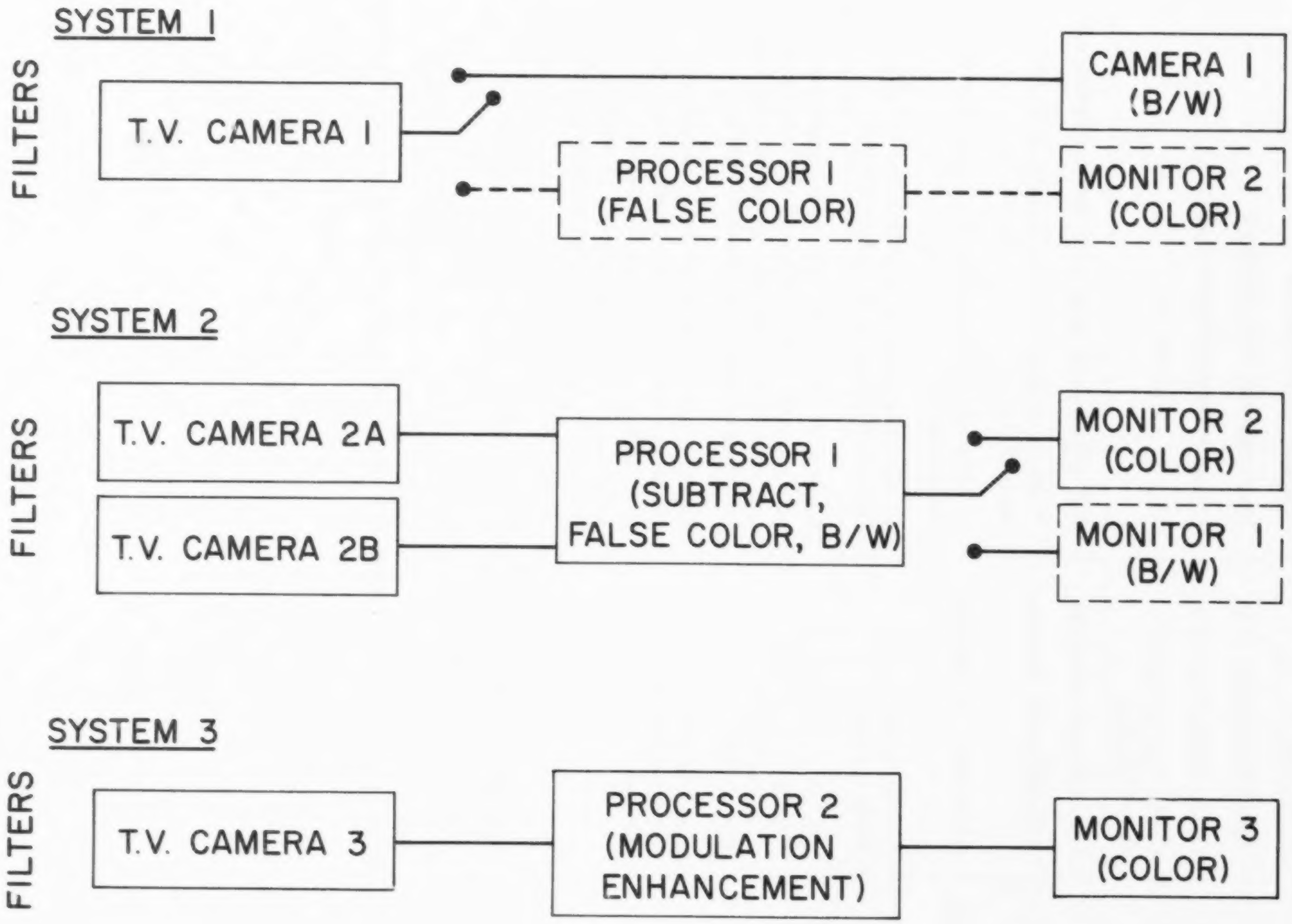

Figure 1. Schematic of basic systems.

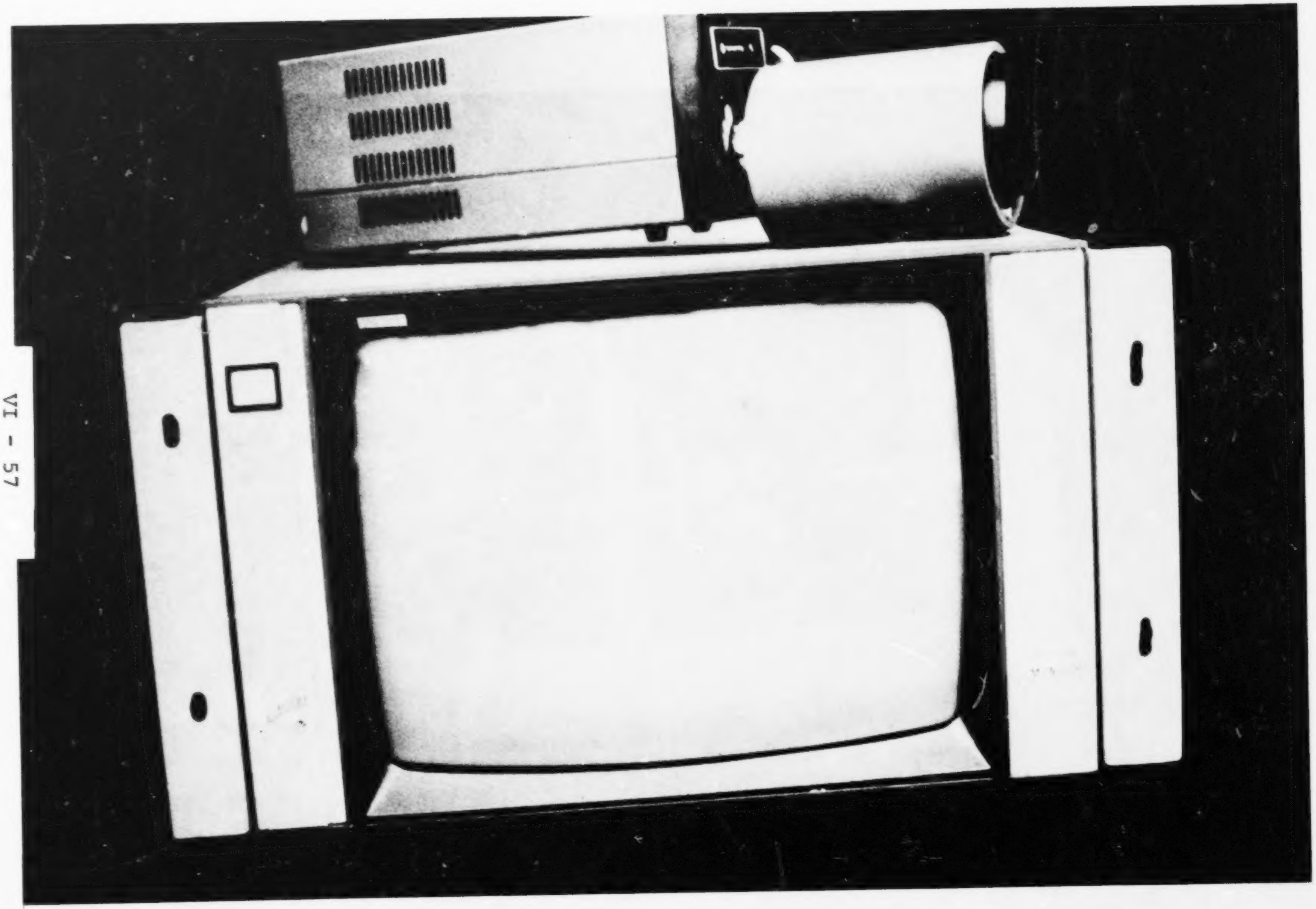

Figure 2. Conventional TV camera, with zoom lens, and monitor.

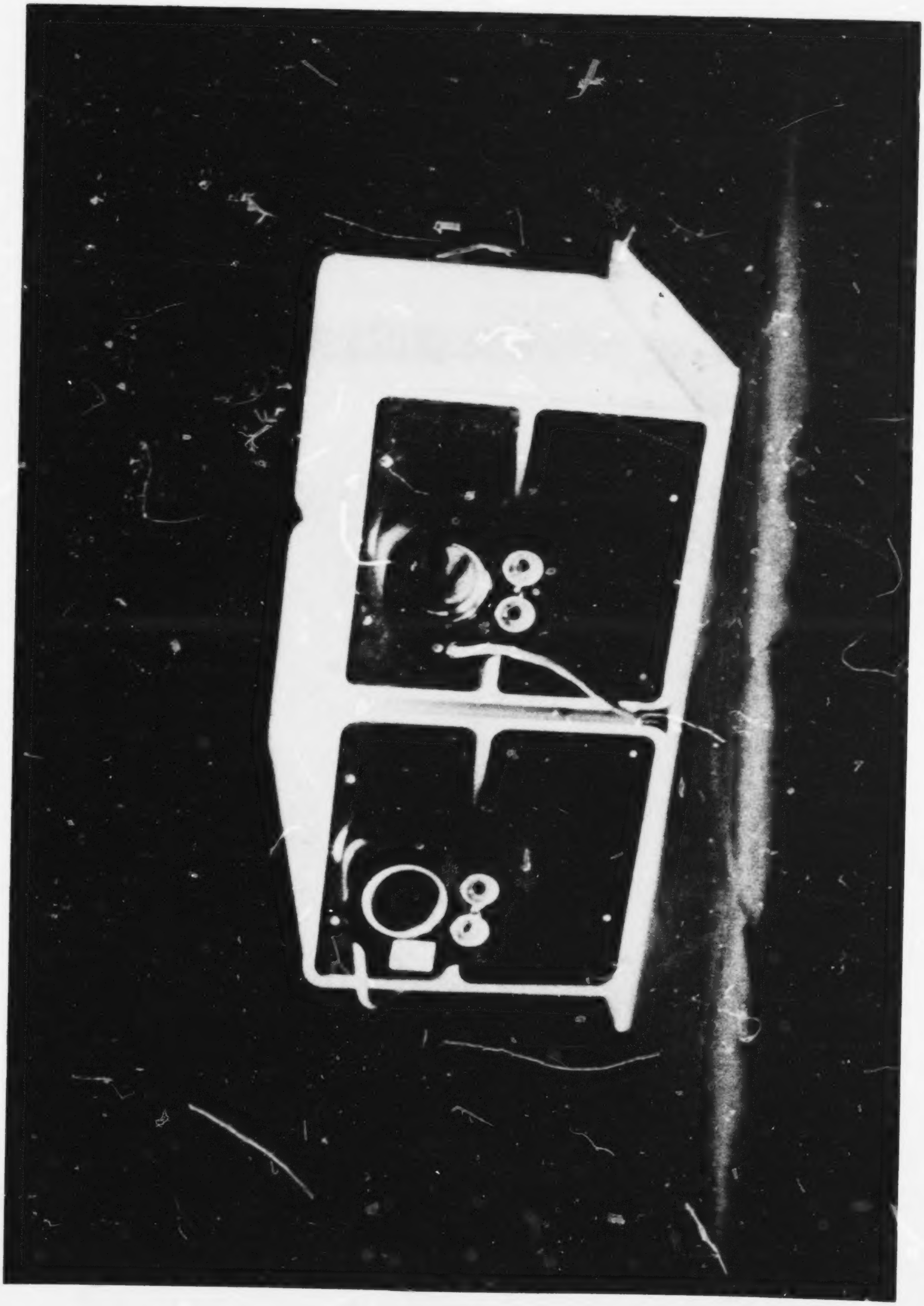

Figure 3. Two bore-sighted TV cameras.

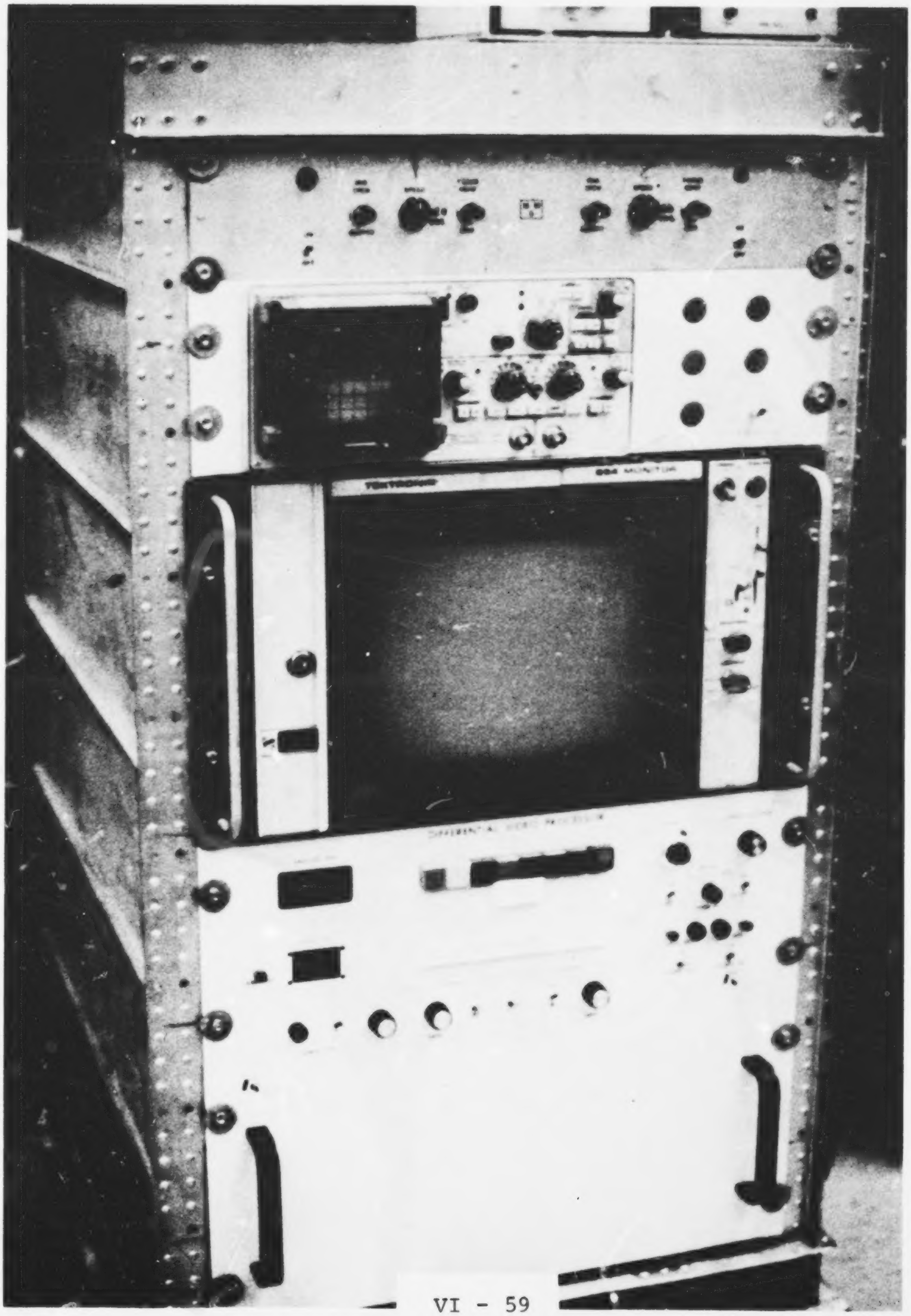

Figure 4. Processor, monitor, and auxiliary equipment used for system 2.

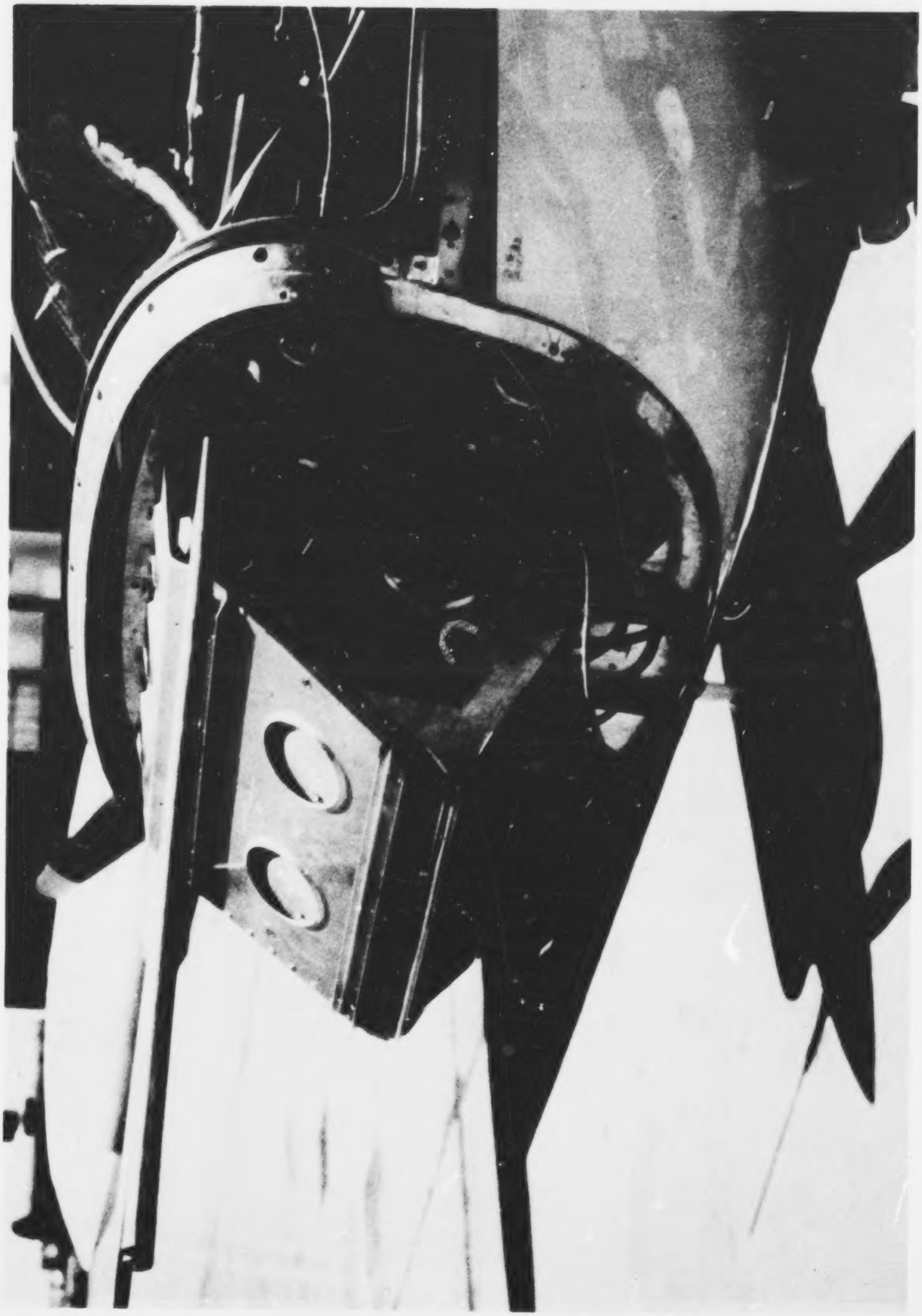

Figure 5. TV cameras mounted in nose of Cessna 402, shroud removed.

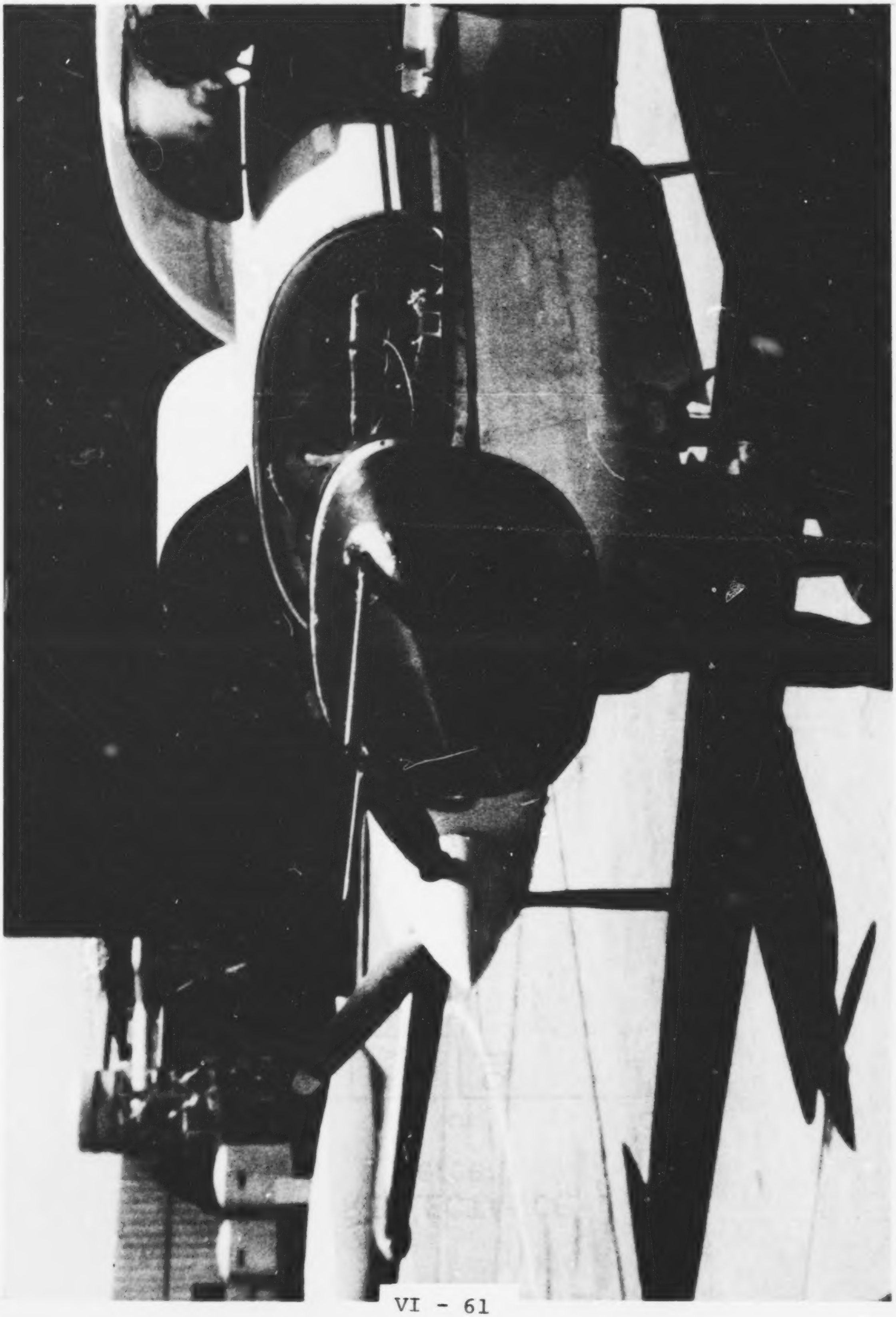

Figure 6. Nose-shroud of Cessna 402 modified to accommodate TV cameras.

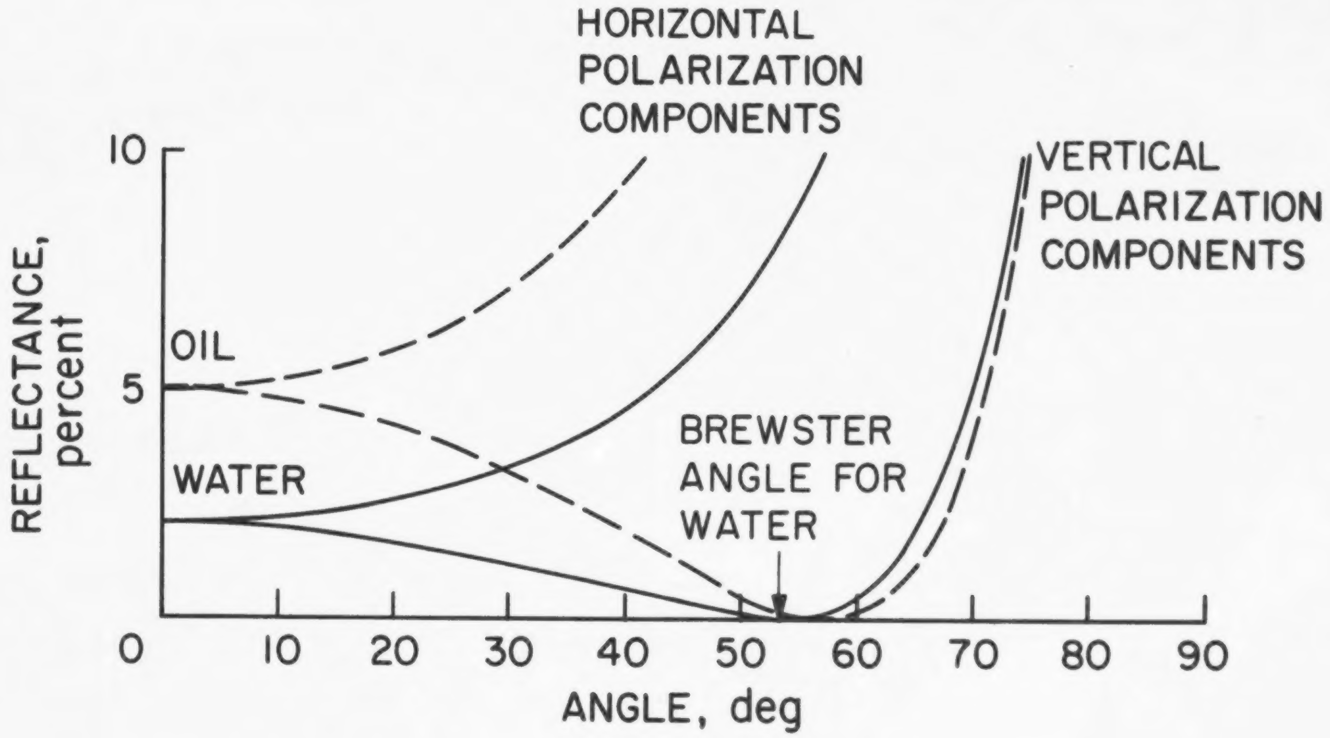

Figure 7. Reflectance of polarization components as a function of the angle of incident light for oil and water; the index of refraction for water is 1.34, and the index for oil is 1.57.

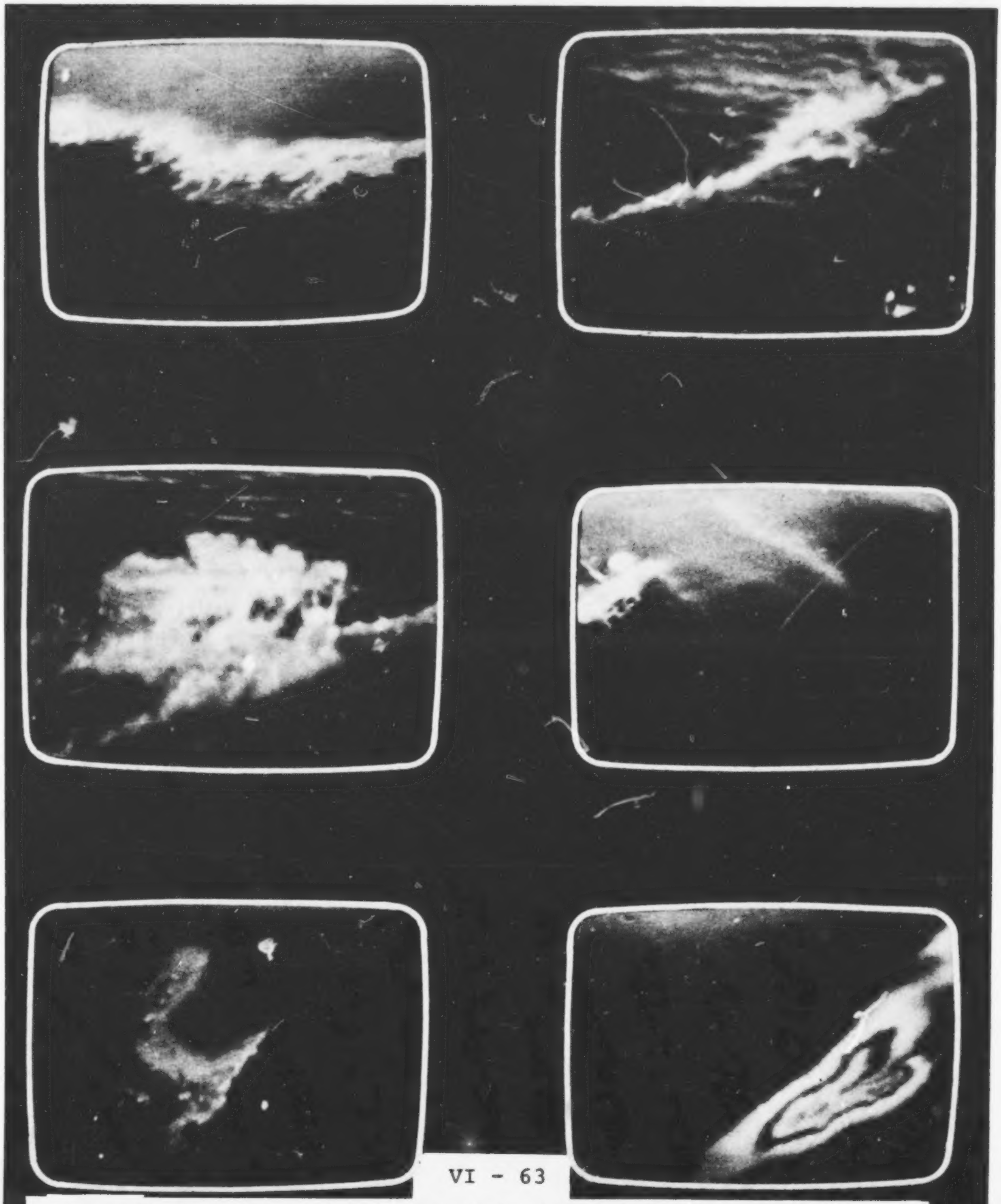

Figure 8. Examples of imagery acquired over natural slicks in the Santa Barbara channel; imagery acquired with a conventional TV camera containing a silicon-diode-array image tube, filtered with a Corning 7-54 filter and a polarizer oriented to transmit the horizontal polarization component.

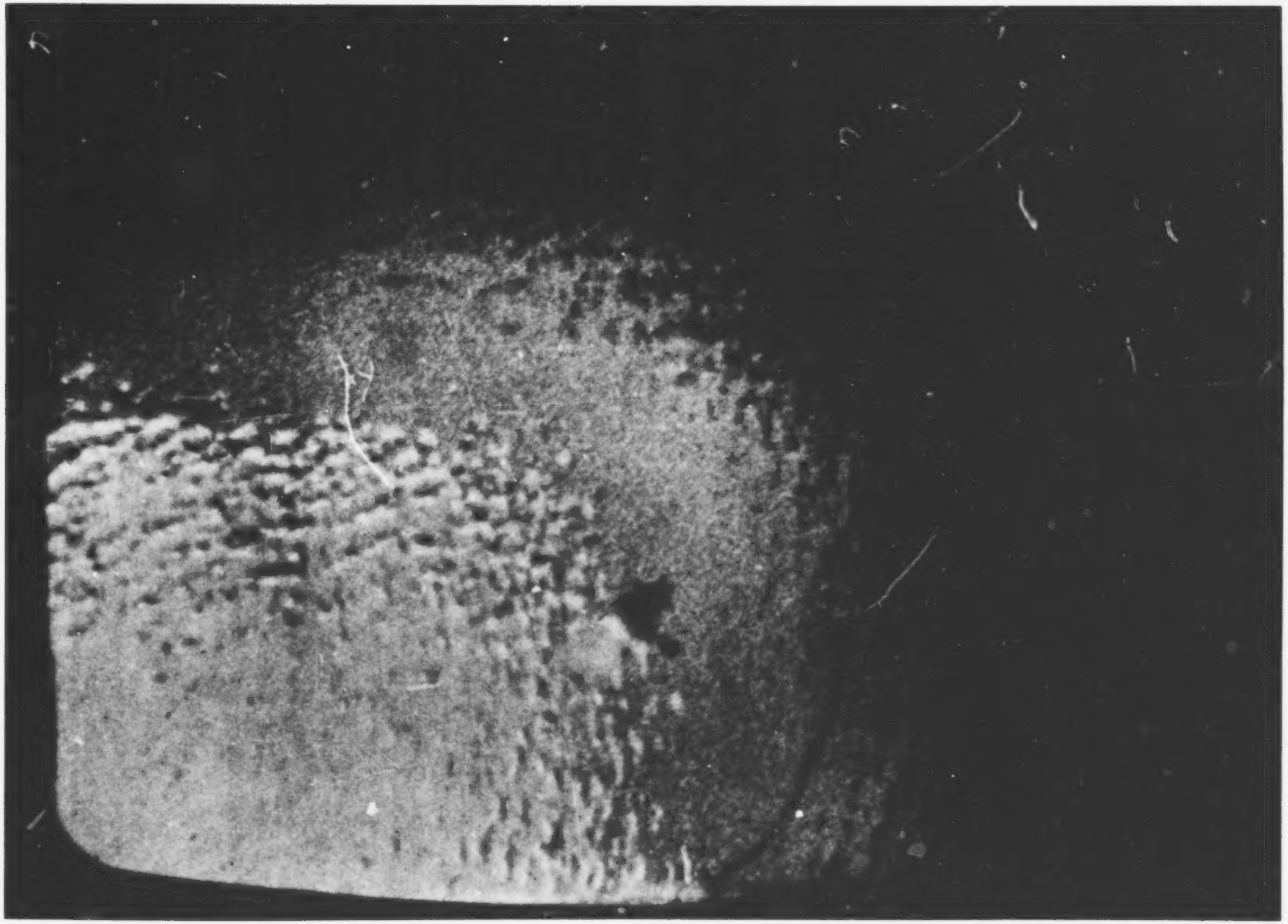

Figure 9. Sun-glint effects on video imagery.

Measurements of the Distribution and Volume of Sea-Surface Oil Spills Using Multifrequency Microwave Radiometry

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ABSTRACT

Multifrequency passive microwave measurements from aircraft have been made of eight controlled marine oil spills. It was found that over 90 percent of the oil was generally confined in a compact region with thicknesses in excess of 1 mm and comprising less than 10 percent of the area of the visible slick. It is shown that microwave radiometry offers a means to measure the distribution of oil in sea-surface slicks and to locate the thick regions and measure their volume on an all-weather, day-or-night, and real-time basis.

PROBLEM STATUS

An interim report on a continuing NRL problem.

AUTHORIZATION

NRL Problem G01-08
Project DOT/USCG 2-21881

Manuscript submitted April 6, 1973.

MEASUREMENTS OF THE DISTRIBUTION AND VOLUME OF SEA—SURFACE OIL SPILLS USING MULTIFREQUENCY MICROWAVE RADIOMETRY

There is mounting concern by the public and governmental agencies over the ever-increasing number of marine oil spills and the more serious resulting pollution. Before appropriate corrective action can be taken, a knowledge of the nature, thickness, areal extent, direction, and rate of drift of the oil spill must be promptly established. This requires a detection and measurement system capable of rapidly responding to a requirement of surveying large and often remote and inaccessible waters on a nearly all-weather and day-or-night basis.

Reliable determination of oil-film thickness is of major importance. It is the film thickness along with areal extent which allows the volume of the slick to be estimated. A knowledge of the volume of oil is essential for litigation and damage claims resulting from major oil spills, as well as for assessing the impact of the spill on marine life and environment. A knowledge of the oil distribution and the location of those regions containing the heaviest concentration of oil would enable the most effective confinement, control, and clean-up of the oil and perhaps is most important.

Sea-surface oil spills do not spread uniformly nor without limit (1, 2). Thick regions which contain the majority of oil are formed and are surrounded by very much thinner and larger slicks. For example, in controlled oil spills of 200 to 630 gallons (760 to 2380 liters), which will be described in detail later, the oil typically formed a region with a thickness of 1 mm or more containing more than 90 percent of the oil but comprising less than 10 percent of the area of the visible slick. The remaining oil formed a large slick, hundreds of times thinner, surrounding the thick region.

Microwave radiometry offers a unique potential for determining oil-slick thicknesses greater than about 0.05 mm. The apparent microwave brightness temperature is greater in the region of an oil slick than in the adjacent unpolluted sea by an amount depending on the slick thickness. In effect the oil film acts as a matching layer between free space and the sea enhancing the brightness temperature of the sea. The calculated* increase in microwave brightness temperature due to an oil slick above that due to the unpolluted sea as a function of slick thickness is shown in Fig. 1 for the three microwave frequencies at which measurements were made. As the thickness of the oil film is increased, the apparent microwave brightness temperature at first increases and then passes through alternating maxima and minima, due to the standing-wave pattern set up by the sea surface. The maxima and minima occur at successive integral multiples of a quarter wavelength in the oil. By using two or more frequencies, thickness ambiguities introduced by the oscillations can be removed and the film thickness determined for a wide range of thicknesses.

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* The reflection coefficients for a smooth dielectric material covered by a uniform dielectric film of finite thickness, necessary to calculate the brightness temperature, are given in Ref. 3.

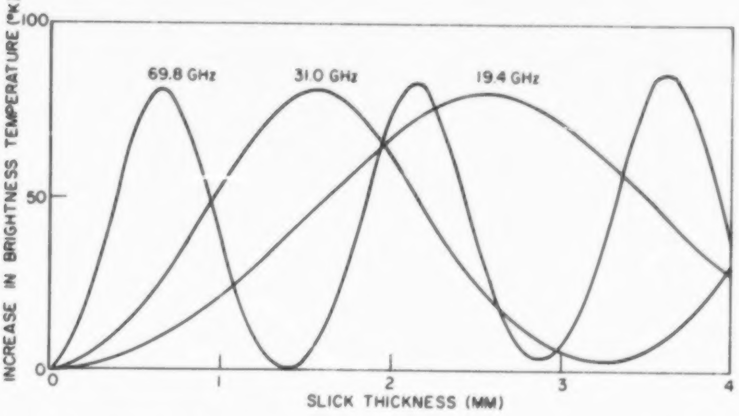

Fig. 1 — Calculated increase in microwave brightness temperature due to an oil slick above that due to the unpolluted sea as a function of slick thickness at 19.3, 31.0, and 69.8 GHz. The calculations are at 0° incidence angle for a smooth sea at a temperature of 20°C and salinity of 35 ppt covered by a uniform oil film with a complex dielectric constant of 2.1 − 0.01*j*.

To verify the calculated behavior with film thickness and to measure the dielectric properties of the three oil types used in the controlled ocean oil spill tests, microwave radiometric measurements were made using a small test tank. The tank was filled with fresh water, and then a known volume of oil was added to the surface. The incremental increase in the oil-film thickness resulting from the addition of oil was calculated assuming uniform spreading of the oil over the surface area of the tank. Measurements were made for No. 2 fuel oil and No. 4 and No. 6 crude oils. Number 2 fuel oil spread uniformly over the tank even for thicknesses as small as 0.1 mm. However No. 4 and No. 6 crude oils tended to form lenses or blobs until the entire tank surface was covered. This required thicknesses in excess of about 4 mm, after which the oils apparently did spread uniformly for small incremental increases. Therefore the results for these oils are less accurate than those obtained for No. 2 fuel oil. The complex dielectric constant of the oil was determined by adjusting it to obtain the best fit of the calculations to the measurements. The measurements for No. 2 fuel oil and the best-fitting calculated curves are shown in Fig. 2. The complex dielectric constant $\epsilon_1 - j\epsilon_2$, determined from the measurements for No. 2, No. 4, and No. 6 oils, is given in Table 1.

The measured antenna temperature, rather than brightness temperature, is given in Fig. 2 to present the magnitudes that were actually observed during the observations. The antenna temperature is the average of the brightness temperature over all directions, weighted by the antenna response pattern (4). That is,

$$T_A = \frac{\int_{4\pi} T_B(\theta, \varphi)\, f(\theta, \varphi)\, d\Omega}{\int_{4\pi} f(\theta, \varphi)\, d\Omega}, \qquad (1)$$

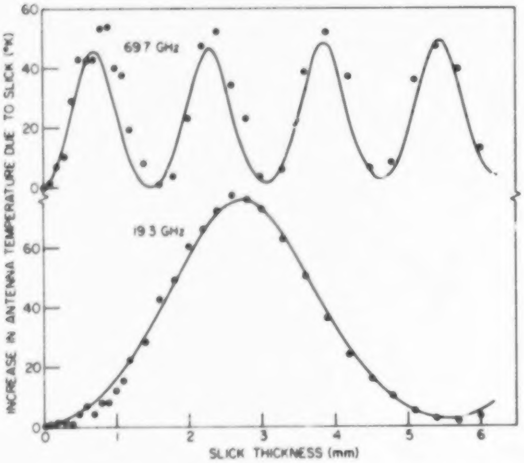

Fig. 2 — The data are measurements at 19.3 and 69.8 GHz of the increase in antenna temperture due to No. 2 fuel oil spread over a smooth water surface in a test tank as a function of film thickness. The curves represent the calculation which best fit the measurements.

where $f(\theta,\varphi)$ is the normalized antenna response pattern and $T_B(\theta,\varphi)$ is the total brightness temperture in the direction θ,φ and is composed of not only the radiation emitted by the sea surface but also the downwelling sky radiation reflected by the surface as well as the emission and attenuation of the atmosphere between the surface and the radiometer. Atmospheric effects are usually less than 10 percent for observational frequencies away from the water-vapor absorption line at 22.235 GHz and below about 40 GHz, and in general approximate corrections can be applied to partially remove them.

A series of eight controlled oil spills was conducted during the period August 1971 through August 1972 in cooperation with the NASA-Wallops Island Station, the Virginia Institute of Marine Science, and the U. S. Coast Guard to investigate the possiblity of determining the thickness of an oil slick using passive microwave radiometry. The spills, of from 200 to 630 gallons (760 to 2380 liters) of either No. 2 fuel oil or No. 4 or No. 6 crude oil, were performed in accordance with the guidelines established by the Environmental Protection Agency for the discharge of oil for research purposes (5). All of the spills were conducted in relatively calm sea conditions of less than 2-m swell and 10-m/s surface winds. The oil was transported in 50-gallon (190-liter) drums to the ocean test site, about 10 mi (16 km) east of Chesapeake Light Tower off the east coast of Virginia. The drums were off-loaded, herded together, and emptied from small rubber boats in a manner so as to obtain as nearly an undistrubed point release as possible.

The documentation of "ground truth" gathered included the type and volume of oil spilled, in situ measurements of oil-slick thickness, and airborne natural and color IR photography and thermal IR imagery, as well as the environmental parameters of sea temperature, air temperature, relative humidity, wind speed and direction, sea state, and general weather and cloud conditions. The oil in two spills was dyed with an oil-soluable

Table 1
Measured Complex Dielectric Constant of Oil

Oil Type	Temperature (°C)	Complex Dielectric Constant	
		f = 19.3 GHz	f = 69.8 GHz
No. 2 Fuel	19	ϵ_1: 2.10 ± 0.05 ϵ_2: $0.01\,^{+\,0.02}_{-\,0.01}$	ϵ_1: 2.10 ± 0.05 ϵ_2: $0.01\,^{+\,0.02}_{-\,0.01}$
No. 4 Crude	26	ϵ_1: 2.4 ± 0.1 ϵ_2: 0.06 ± 0.04	ϵ_1: 2.2 ± 0.1 ϵ_2: 0.07 ± 0.04
No. 6 Crude	26	ϵ_1: 2.6 ± 0.2 ϵ_2: 0.05 ± 0.05	ϵ_1: 2.6 ± 0.2 ϵ_2: 0.05 ± 0.05

red dye to aid in establishing the distribution of oil over the sea surface. The dye allowed the thick regions of oil to be easily identified visibly. Figure 3 is a series of drawings traced from color photography of the July 11, 1972, oil spill. This spill consisted of 630 gallons (2380 liters) of No. 2 fuel oil dyed red. The sea conditions were calm, with about 1-m swell and winds of 2 - 4 m/s. The outer line in each drawing represents the extreme edge of the visible slick, the next inner line is the region of color fringing when visible in the photograph, and the crosshatched area is the region of thick oil. The oil formed a well-defined thick region surrounded by a very much larger and thinner region. In situ thickness measurements showed the oil to be 2.4 ± 0.3 mm thick at spots in the crosshatched region and typically 2 to 4 μm thick outside this region. The thick inner region spread at a much slower rate than the total slick. This is shown in Fig. 4 where the area of the inner region and the total area of the visible slick are displayed as a function of time on a log-log plot. If the dashed lines are taken to represent the measurements, the total area grew at a rate proportional to the time to the 0.6 power; the thick region grew at a rate proportional to time to the 0.2 power. The spreading rate of the total area most nearly matches the gravity-viscous spreading phase described theoretically by Fay (6), which grows at a rate proportional to the square root of the time. It is somewhat slower than spreading rates reported by Guinard (7) or by Munday et al., (8). However the spreading rate is dependent on many variables—such as initial volume, age, density and viscosity of the oil, the surface-active materials present, interfacial surface tension, surface wind, sea state, and surface current present—and will vary widely. Most significant is the dichotomous behavior of the oil, dividing clearly into a thick, relatively compact region surrounded by a second much larger and thinner region. All of the spills conducted of each oil type exhibited this behavior. It may well be due to small quantities of surface-active materials in the oil which spread more rapidly than the bulk of the oil, surrounding it, inhibiting its growth, and thus containing and controlling the oil.*

The microwave observations were taken using the NASA-Wallops Island DC-4 aircraft. Measurements were made at 19.4 and 69.8 GHz for the initial spills and at 19.4 and 31.0

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* Private communication with W. D. Garrett.

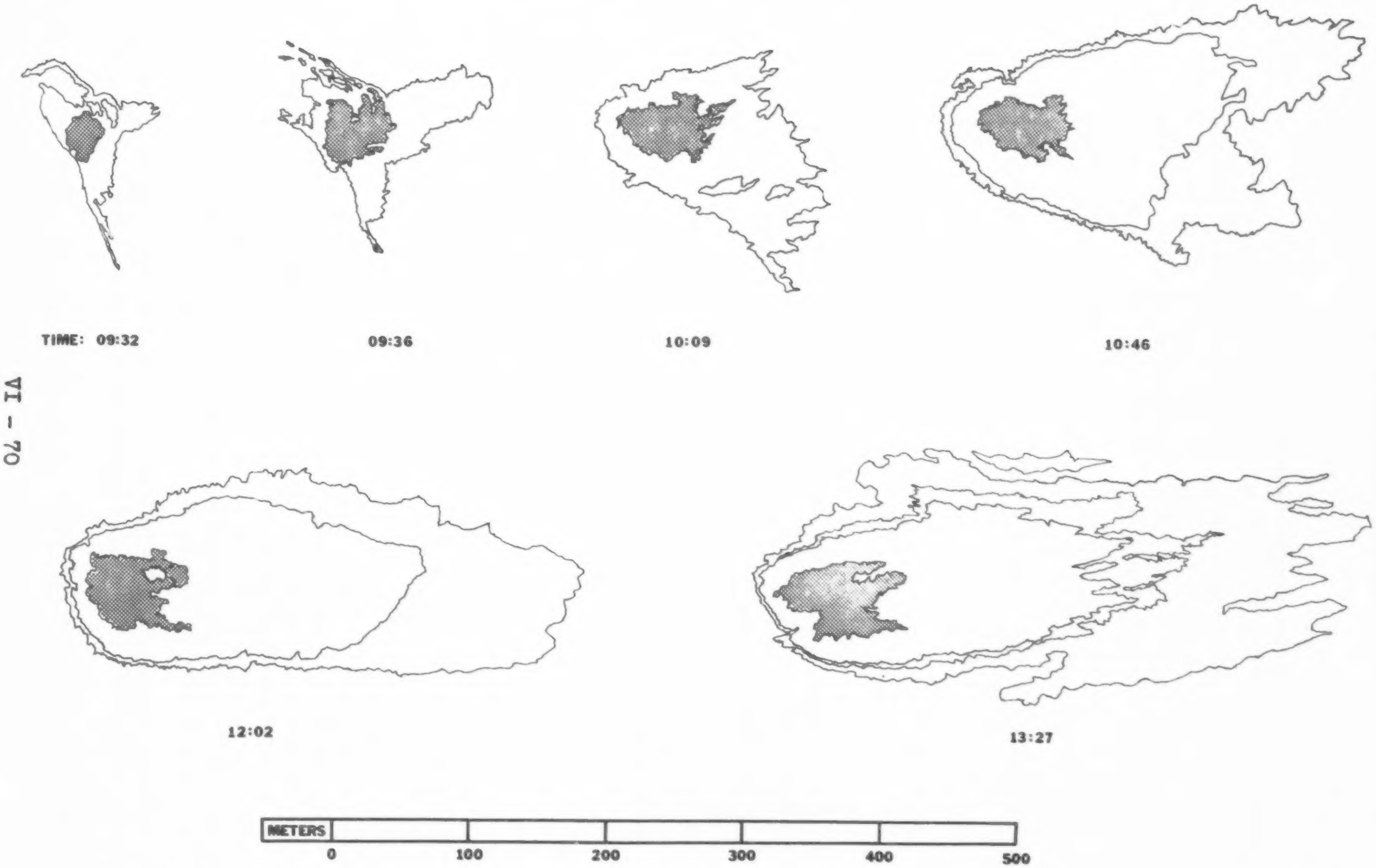

Fig. 3 — Tracings of color photography of the oil slick resulting from a controlled oil spill of 630 gallons of No. 2 fuel oil. The oil had been dyed red to allow the thick regions of oil to be identified visibly. The outer line in each drawing represents the extreme edge of the visible slick, the next inner line is the region of color fringing when visible in the photograph, and the crosshatched area is the region of thickest oil.

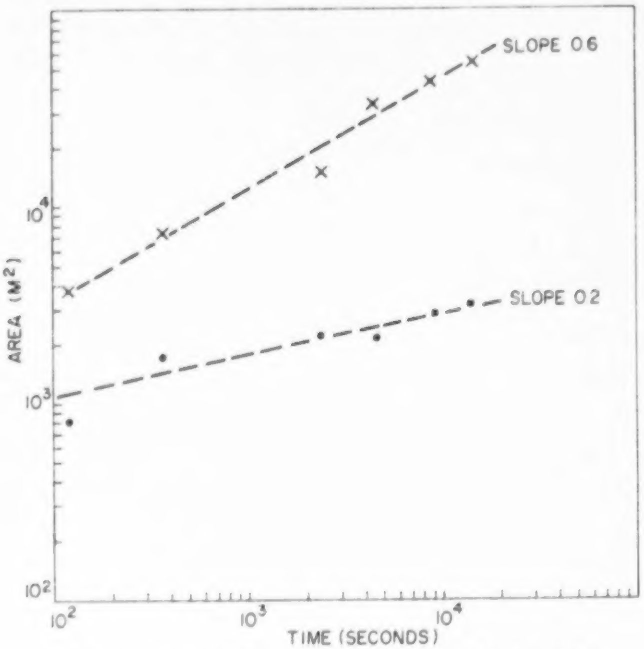

Fig. 4 — Area of the inner thick region (dots) and the total area of the visible slick (crosses) measured from the photography of the oil spill represented in Fig. 3 is plotted versus the time the picture was taken. The dashed lines are possible representations of the measurements.

GHz for the last three spills. The latter combination proved more effective for the oil thicknesses of up to several millimeters which were encountered. The half-power antenna beamwidth at all three frequencies was 7.2 degrees, which gave a beam spot on the surface of about 50 ft (15 m) for the aircraft altitude used of about 400 ft (122 m). A two-dimensional antenna-temperature map of the oil slick was built up by making repeated aircraft passes over the extent of the slick. Approximately 15 to 30 minutes before and after the nominal time of the map were required to acquire sufficient scans for the map.

Contour maps of the increase in antenna temperature above that for the unpolluted sea at 19.4 and 31.0 GHz are shown at the right in Fig. 5 superimposed on the outline of the visible slick for the spill of July 11, 1972. These antenna-temperature distributions were used to derive the thickness contours shown at the bottom left of the figure. The antenna temperatures and derived thicknesses are weighted averages over the antenna beam, as given by Eq. (1). The half-power beam spot on the surface is represented by the small circle. The microwave signals coincide closely with the region of thick oil and show that average thicknesses over the antenna beam of up to 1.5 mm are present in good agreement with in situ spot measurements in this area of 2.4 ± 0.3 mm. Integration of the thickness contours derived from the microwave data gives a volume of 650 ± 65 gallons (2460 ± 246 liters), which taken with the volume of oil spilled of 630 gallons (2380 liters) indicates that nearly all of the oil is in the thick region. This is consistent with in situ measurements of film thicknesses of 2 — 4 μm outside the thick region, since only 15 to 30 gallons (57 to 114 liters) of oil would be needed to cover the entire

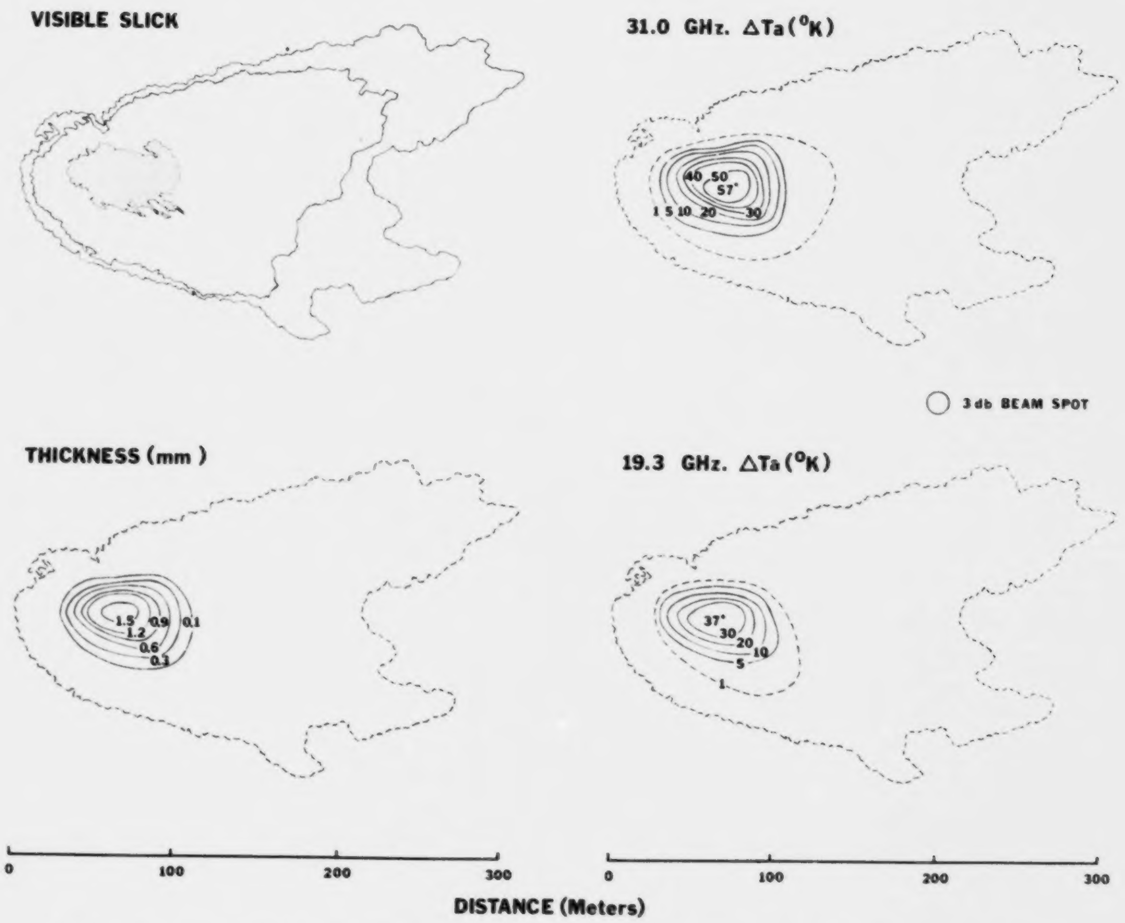

Fig. 5 — The upper-left-hand drawing is a tracing of a color photograph of the oil slick resulting from a controlled spill of 630 gallons of No. 2 fuel oil. The oil had been dyed red to allow the thick regions of oil to be identified visibly. The outer line is the extreme edge of the visible slick, the next inner line is the region of color fringing, and the crosshatched area is the region of thick oil. The antenna temperature measured at 19.3 and 31.0 GHz are shown at the right superimposed on the outline of the visible slick. The thickness contours derived from the microwave data are shown at the bottom left.

area of the visible slick of 33×10^3 m^2 with a uniform film to thicknesses of $2 - 4$ μm. The ratio of slick thickness in the two regions of nearly 1000 also shows that nearly all of the oil is located in a small region of the slick.

The microwave measurements of all of the oil spills of each oil type showed results very similar to those just described for the spill of July 11, 1972. The slicks always formed an identifiable region with film thicknesses of a millimeter or more and containing the majority of oil, which was surrounded by a very much larger and thinner slick which contained very little of the oil. In general the thick region contained more than 90 percent of the oil in less than 10 percent of the area of the visible slick. It was always possible to locate and delineate the thick region solely form the microwave observations, and the total volume of oil present derived from the microwave measurements was within about 25 percent of the volume of oil spilled.

In summary, multifrequency passive microwave radiometry offers the potential to measure the distribution of oil in sea-surface oil slicks and to locate the thick regions and measure their thickness and volume on an all-weather, day-or-night, and real-time basis. As such it should prove a useful tool in the confinement, control, and cleanup of marine oil spills.

ACKNOWLEDGMENTS

The authors thank S. R. MacLeod and J. A. Modolo for their fine work in the design, construction, calibration and installation of the radiometers and for their help in taking the measurements. We express our appreciation to the staff at NASA-Wallops Island Station for their invaluable assistance and aircraft support and to the Virginia Institute of Marine Science for their aid in conducting the oil spills and obtaining ground truth. This work was sponsored by the U. S. Coast Guard under contract number Z-70099-2-21881.

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THE NATIONAL ENVIRONMENTAL MONITORING SYSTEM

by

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ABSTRACT

The first NASA developed GOES (Geostationary Operational Environmental Satellite) is scheduled for deployment early in 1974. After engineering checkout its operational control will be assumed by NOAA (National Oceanic and Atmospheric Administration). NOAA has planned to make the communications relay (transponder) capability of the satellite available to all agencies planning or operating Environmental Monitoring Systems comprised of automatic unattended Data Collection Platforms (DCP). The objective of this paper is to provide a review of the capabilities of the satellite communications system, its developmental status as well as similar descriptions for some of the DCP planned for incorporation in the overall system which has been titled 'The National Environmental Monitoring System." The applicability of the system to water pollution control systems is discussed and some recommendations for specific pollutant sensor developments are made.

SYSTEM DESCRIPTION

The "National Environmental Monitoring System' (Figure 1) is based on a plan by the United States to deploy two Geostationary Operational Environmental Satellite (GOES) over the western hemisphere. The first of these is scheduled for launch early in 1974. The European Space Research Organization, the USSR, and the Japanese each plan to launch a satellite in their segment of the belt. The five satellites, all communications-compatible, will form a worldwide belt of Environmental Satellites.

Each GOES satellite (Figure 2) will have the capability to relay data from 40,000 Data Collection Platforms every six hours. The Data Collection Platforms, consisting of both land-and water-based stations, will be equipped with environmental sensors and radio sets which will transmit the digital sensor signals over one of 150 possible UHF channels at 100 bits per second.

One of the principal applications of the Data Collection Platforms will be that of hydrological monitoring of fresh water resources. Fresh water control is necessary not only to agriculture, for flood control and irrigation, but to all citizens as a vital resource for health and quality of life. The degree of water pollution in our streams, rivers, and lakes is directly proportional to the volume of water available for dilution and natural processing of waste materials. Accordingly, until the zero pollution discharge objectives of the Environmental Protection Agency (EPA) are achieved, water resource conservation and control will continue to play a vital role in water pollution control.

The hydrological stations will be installed in grids across major water sheds to measure precipitation, water levels, water flow, and in some instances water quality. The data from these grids of DCP's will be used to manage the retention or release of water by the existing networks of flood control dams as well as to predict flash floods.

The National Environmental Research Center (NERC) in Cincinnati have been developing unattended water quality monitoring stations. (Figure 3) They have successfully demonstrated the feasibility of transmitting water quality data via satellite from the Great Miami River Pollution Monitoring Station. (Figure 4) Plans have been made to equip this station with the capability of monitoring specific pollutants (heavy metals) and to transmit the data via the ERTS satellite. The specific pollution monitoring equipment will be designed in ruggedized form for compatibility with shipboard environmental parameters so that the modules can be assembled to provide a pollution monitoring capability for relatively small patrol vessels, as shown in Figure 5. Both EPA and the USCG currently operate a number of such vessels which perform visual and sample acquisition monitoring functions.

Manual shipboard monitoring on a large scale can be prohibitively expensive. Water Quality Monitoring Buoys (Figure 6) equipped with low power, reliable sensors (currently available or in development) provide a cost effective alternative. Typical parameters that can be monitored from a buoy include DO, pH, temperature, conductivity, chlorophyl and turbidity. An outline drawing of a developmental chlorophyl-turbidometer package is depicted in Figure 7. The buoy Data Collection Platform becomes particularly attractive if the monitoring data suite includes meteorological and oceanographic parameters such as currents, temperature profiles, etc. When synoptic reporting is required, the buoy DCP become economically mandatory.

The National Weather Service Automation of Field Operation and Services (AFOS) Program and related programs provides for automation of both manned and unmanned weather stations. An unmanned automated weather station is depicted in Figure 8. This station will be battery powered and modular for packaging into remote areas. The highly directional antenna can be manually trained to the calculated GOES satellite elevation and azimuth. The directivity of the antenna reduces DCP transmitter power and thus permits a smaller battery pack.

The National Oceanic and Atmospheric Administration plans to deploy a number of moored meteorological buoys (similar in configuration to the experimental buoys shown in Figure 9) off the North American Pacific coast. Data from these buoys will be used locally to provide maximum safety to the Trans-Alaskan Pipeline tankers as well as to improve weather forecasting over the North American continent. The tankers and similar platforms of opportunity, as shown in Figure 10, may be equipped with the sensors and electronics installed in the buoys to provide mobile automatic meteorological platforms. Another mobile meteorological platform is the Drifting Meteorological Buoy developed by the NOAA National Data Buoy Office. (Figure 11) This drifting buoy is equipped with a position location system utilizing NNSS or Omega data to report buoy position along with the environmental data.

REGIONAL AND LOCAL MONITORING SYSTEMS

The National Environmental Monitoring System can be used to supply data from inaccessable remote DCP's to a regional or local monitoring system, and to report summary data from the regional system into the national system. A Great Lakes Environmental Monitoring System is depicted in Figure 12 as an example of a regional system. In this system, data from the buoys inaccessable land stations will be transmitted via the GOES satellite to the CDA station, and then back to the Regional Data Acquisition and Processing Center via land line. To fulfill all data requirements, the Great Lakes Environmental Monitoring System will, on a selective parameter module basis, be capable of providing meteorological and limnological, as well as water quality data.

The need and requirements for automatic unattended Water Quality Monitoring Systems have been fully established and documented (see References 1,2, and 3). In summary, the systems must provide the following

1. Rapid intelligence and alarms
2. Continuous surveillance

3. Effective enforcement
4. Data for water quality models
5. Basis for issuance of permits
6. Effects of natural phenomena
7. Large numbers of measurements
8. Computer analysis of data
9. Cost effectiveness
10. Measurement of specific pollutants
11. Monitoring of water quality trends

It is anticipated that the Great Lakes Water Quality Monitoring Platforms will include fixed land-based stations equipped with modular sensors and electronics as required to perform the measurements to be made at the selected site. In addition, mobile platforms such as trailers or vans and vessels will be used, particularly to investigate critical areas.

An example of a local area monitoring system is the USCG Oil Spill Surveillance System shown in Figure 13. The objective of this system will be to protect a harbor from accidental oil spills through the provision of oil slick sensors mounted on buoys, bridges, piers, buildings etc. Data from these sensors will be telemetered to a central processing control station via radio and hard-wire circuits. After processing, the oil spill detection data could be transmitted via the GOES satellite for action by the USCG and the responsible governmental or civilian organizations involved.

THE GOES COMMUNICATIONS SYSTEM

Figure 14 shows that the major components of the GOES Data Collection System (DCS) are the Command and Data Acquisition (CDA) Station, the GOES spacecraft (SC) and the remotely located Data Collection Platforms (DCP). While the spacecraft carries a family of remote sensors and associated data distribution systems, it is the cross-trapped transponder that is of primary interest to the technical community concerned with earth-based Data Collection Platforms (DCP). Transmission between the CDA and spacecraft is at S-band, while transmission between the field of DCP's and the spacecraft is at UHF. A block diagram of the GOES Data Collection System is shown in Figure 15.

The NOAA National Environmental Satellite Service (NESS) has developed Data Collection Platform Radio Sets (DCPRS) for both mobile (Ship, buoy, and fixed (land-based) Data Collection Platforms (Figure 16)). The fixed-location DCPRS are further provided in self-timed and interrogated configurations. The self-timed sets automatically transmit available data at preset intervals while the interrogated set transmissions are commanded from the CDA station. The specifications for these sets are tabulated in Figure 17.

For the fixed location DCPRS the helical antenna shown in Figure 18 is used. The gain of this antenna is considered to be +10db for link calculation purposes, but careful pointing in the field will yield nearly 13db of gain. For the mobile platforms, an omnidirectional antenna is required; a conical log-spiral antenna with right-hand circular polarization is used. The gain for link calculation purposes is considered to be 4db. To preserve the link margin on the mobile DCP, the transmitter power is increased to 40 watts.

The interrogated DCPRS uses the Interrogation Command and Reply Message Formats shown in Figure 19. The detailed frequency plan is shown in Figure 20. For the DCP to SC reply messages, 150 channels are available Studies have shown that the average transmission from DCP to SC will be 80 seconds in duration; accordingly up to 40,000 DCP transmissions can be processed over a six-hour period. For those messages that require more than the two-minutes maximum DCP reply, the platform may be reinterrogated until all of the data is accumulated.

Wallops Island will perform CDA station functions for the GOES satellite. It will be equipped with the Data Collection Subsystem Control and Demodulator shown in Figure 21. This equipment has the capabilities listed in Figure 22. For the DCP interrogation functions, the DCP addresses will be received over land lines from the computer at the NOAA Suitland Maryland facility, and will be stored in the Data Collection Subsystem. After data formatting, the Data Collection Subsystem transmits interrogation commands to the Data Collection Platforms via the spacecraft and receives data responses from the DCP. The data from the DCP is multiplexed in the Data Collection Subsystem for transmission over unconditioned telephone lines to the computer at Suitland.

SENSOR DEVELOPMENTS

The success of the National Environmental Monitoring System is largely based on the availability of sensors capable of providing accurate measurements for months of unattended operation under adverse operating conditions. NOAA has recognized the problem in the National Data Buoy Program and has supported a meteorological and oceanographic sensor development program which has begun to yield significant results. This agency has recently undertaken the development/evaluation of reliable, low-power water quality sensors compatible with the long-life, unattended requirements of the National Data Buoys. The results of this program will be available to the environmental community late in 1974.

Similar developmental programs should be initiated in analytical instrumentation for specific water pollutants. Figure 23 indicates applicable laboratory analytical methods for the detection/quantification of the pollutant materials listed in the Canadian/US Agreement for Improving Water Quality in the Great Lakes. In general the laboratory equipment is designed for attended operation with some of the functions such as sample pretreatment, transfer and disposal performed by the operator. Further the operator is often required to read meters, log results etc. The ultimate objectvies of analytical sensors development programs must include:

1. Automatic sample acquisition
2. Automatic sample pretreatment
3. Selection of techniques compatible with automation
4. Selection of techniques providing modular assembly of an unattended Data Collection Platform
5. Design for installation in all possible types of platforms
6. Outputs compatible with available communications systems and computer processing

Basic technology and specific related experience are already available to perform unattended analytical sensor development for specific water pollutants. The NERC Laboratory in Cincinnati has extensive experience in Sample Acquisition Systems and Water Quality Sensors. In the area of severe, corrosive, marine fouling environmental the NOAA National Data Buoy Office and the Navy ASW offices and associated industrial contractors have a great reservoir of talent and technical experience. In the area of analytical instrumentation, the Instrument Industry stands ready to make its contributions in design for specific applications. A multi-discipline team of systems-oriented engineers and scientists working under the leadership of the responsible governmental agency and drawing on the extensive technology available can, with minimum risk, assume the challenge to extend unattended monitoring to specific water pollutant control.

The primary objective of this paper is to acquaint the reader with the developmental status of the National Monitoring System. Since the water pollution instrumentation area is the pacing item relative to the full implementation of this system it may be useful to review the development elements of one of the more promising analytical methods. Energy Dispersive X-Ray (EDX) Spectroscopy was chosen since it is a relatively new technique with great potential for rapid and accurate analysis of the heavy metal family of materials. Since pumps, reagents and considerable power consuming equipment are involved with this technique, it is not applicable to buoy platforms but is very compatible with vessels and fixed land platforms.

The first function to be performed is Sample Acquisition (Figure 24). Reliable pumps and inert materials must be selected in combination with filter mechanisms and flushing systems to prevent fouling by marine organism and contamination of the sample. Provisions must be made to capture and hold a sample in response to commands issued by the logic built into the analyzer, or in response to those generated by the data processing computer or operating personnel. The sample from the Sample Tank may be applied to a number of analyzers and their associated pre-treatment equipment.

Figure 25 depicts the Sample Pretreatment envisioned for the EDX analyzer for dissolved heavy metals. The auto-analyzer metering pump draws a 0.1 liter sample which is reagent-pretreated to form the metal precipitates. The sample is passed through a tape filter to collect the precipitates. The filter is then indexed to a position below the x-ray generator and the concentric diode detector for the derivation of the element energy spectrum shown in Figure 26. The detector is shown in greater detail in Figure 27. The output of the lithium drifted silicon diode detector is applied to a mini-computer which functions both as a multi-channel analyzer and a data manipulation device; thus the spectrum shown in Figure 26 does not need to be generated as a display, but can be printed out on one of the many available computer output printers.

The principle of detector operation is based on the generation of secondary x-rays in the sample by illuminating it with low level primary x-rays such as those radiating from a radio-isotope. The secondary x-rays, of unique energy for each element, are columnated and directed through a beryllium window to strike the liquid nitrogen cooled silicon diode. Both the diode and its associated FET pre-amplifier are operated in the liquid nitrogen environment to minimize thermal noise. The secondary x-rays that strike the detector ionize the silicon atoms in the diode, creating electron hole pairs and free electrons proportional to the energy of the incoming x-rays. This signal is amplified and stored in a memory bin corresponding to its energy level. The electronic system can handle up to 20,000 signals per second of various energy levels. The detection process continues over a preset time base in the order of 100 seconds. At the end of the detection process, the memory bins may be read out in the form of an energy spectrum with the energy of each signal identifying the metal and the peak amplitude the concentration. This read-out process can be done automatically in the form of a set of numbers.

The EDX laboratory equipment (shown in Figure 28) has demonstrated sensitivities in the order of 60 parts per billion. The EDX system performs elemental analysis on all material above sodium (Atomic No.11).

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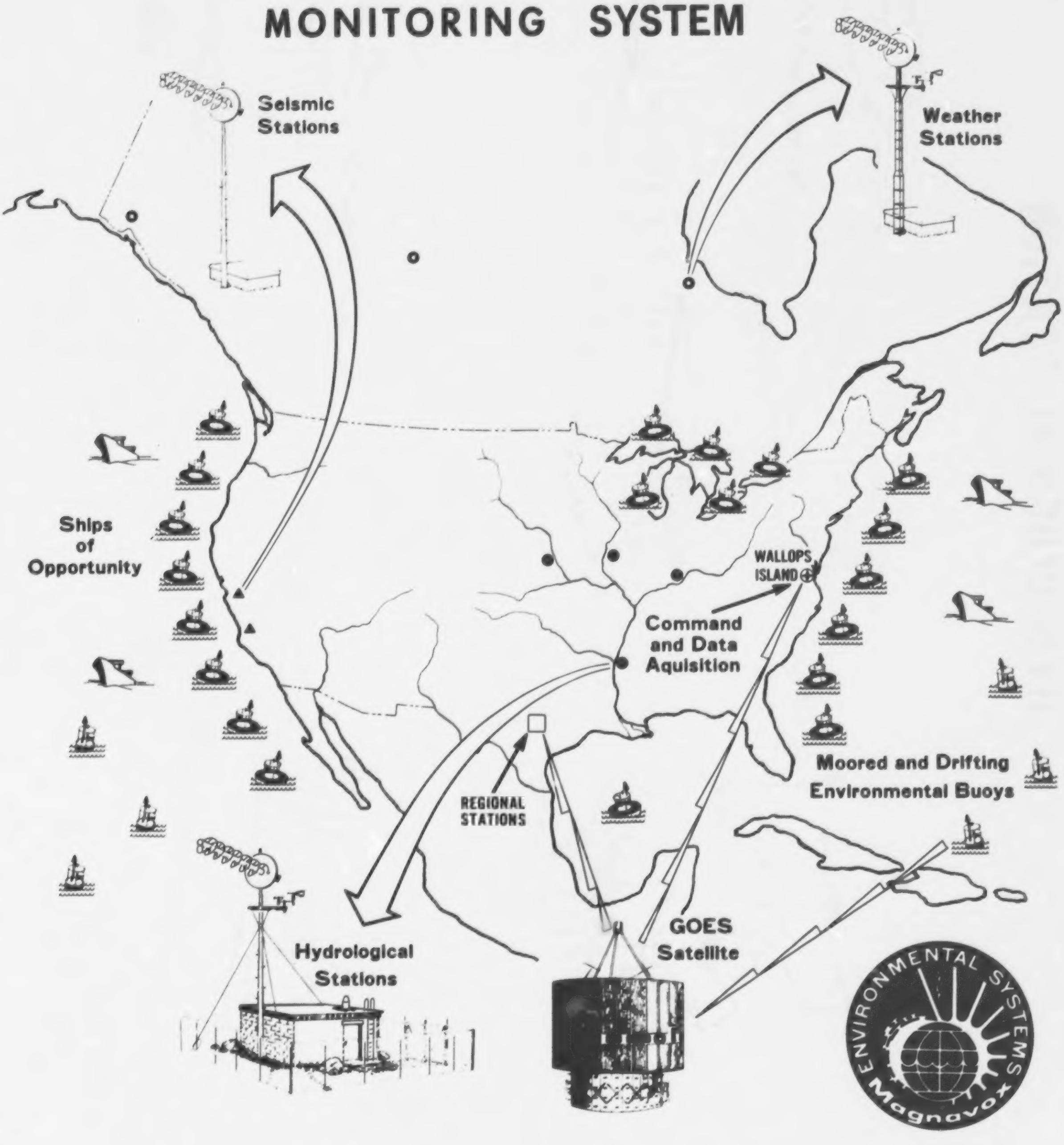
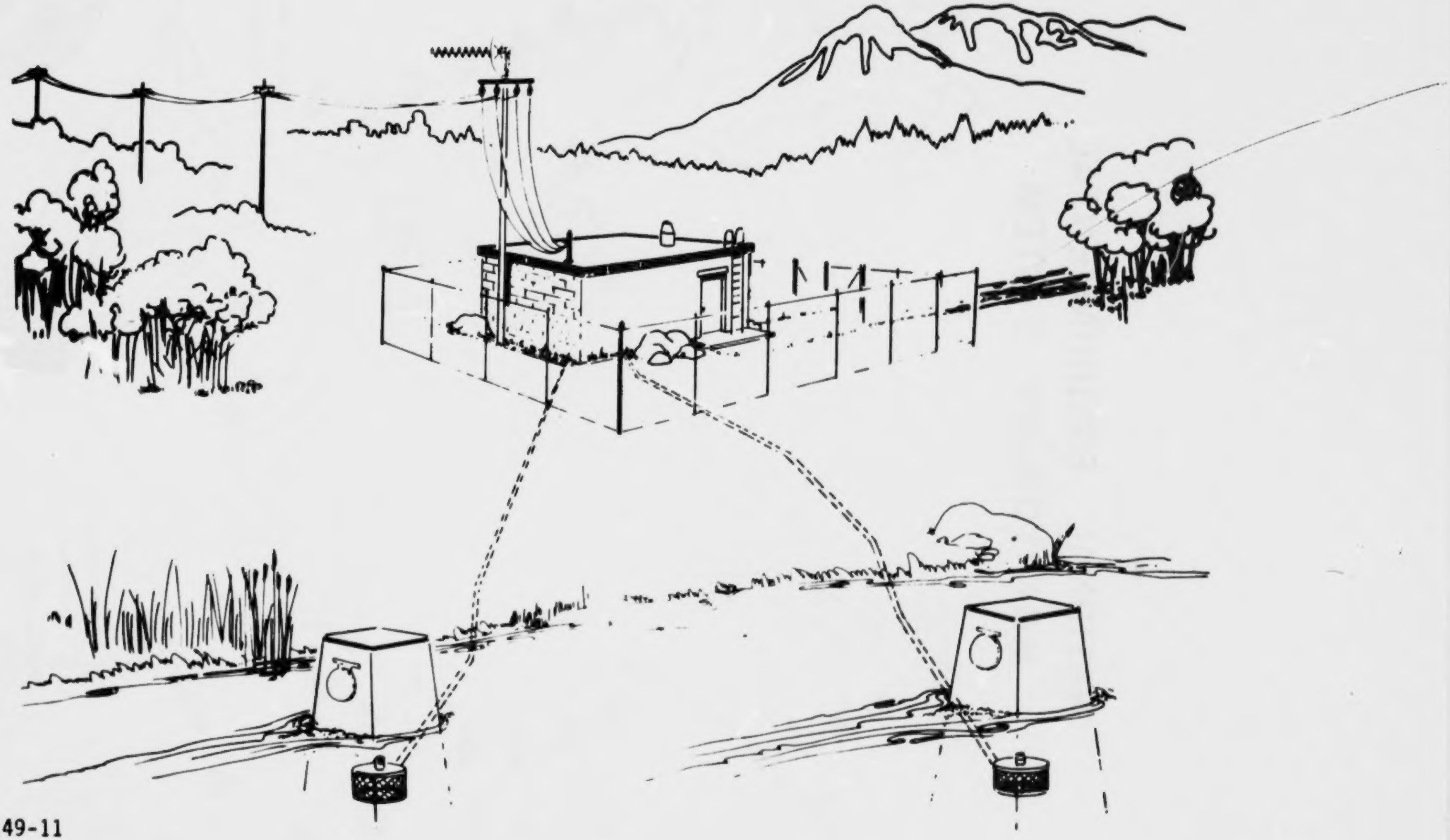
NATIONAL ENVIRONMENTAL MONITORING SYSTEM

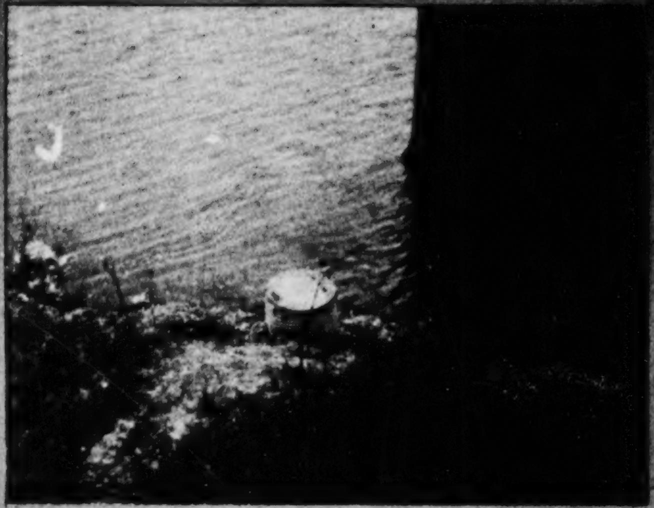


HYDROLOGICAL STATION



FWD149-11

EPA Great Miami River (GMR) Pollution Monitoring Station

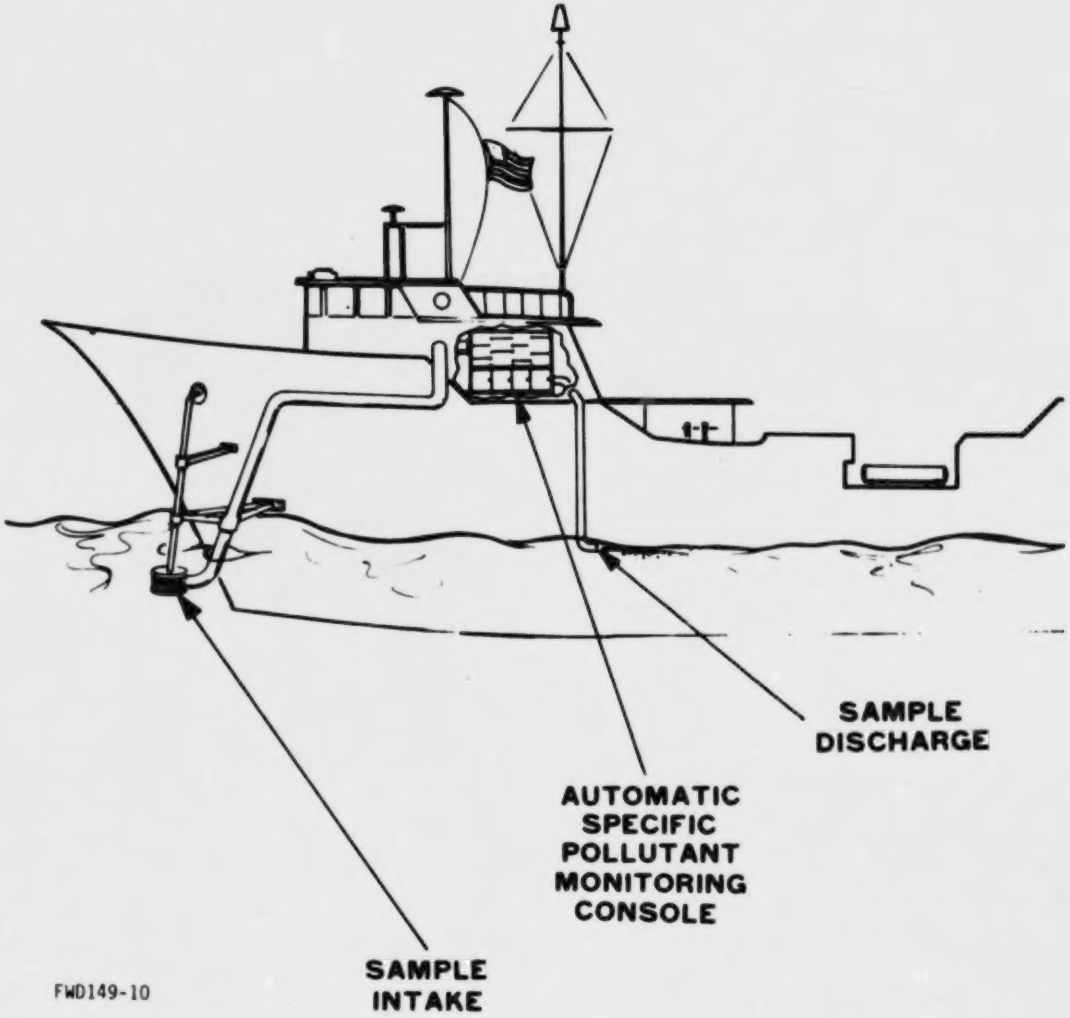


Well Station Water Sample

GMR Monitoring Station

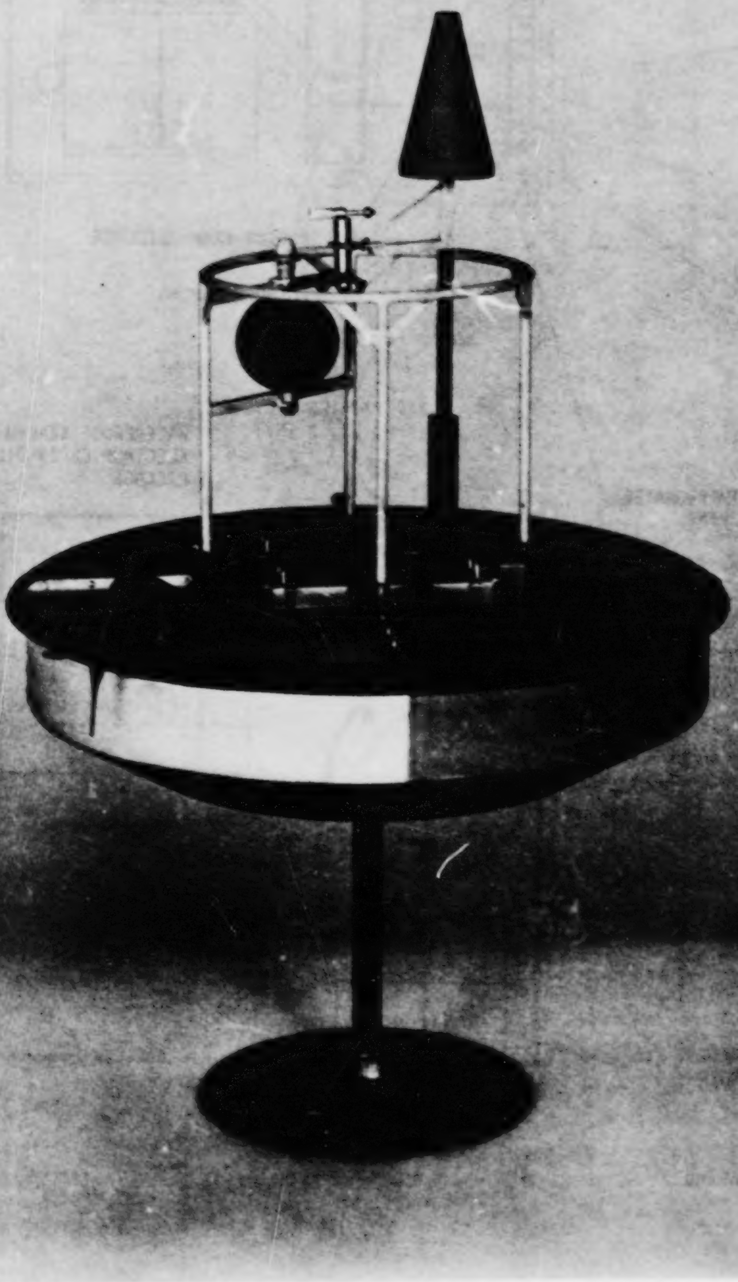
FWD375-37

Pollution Monitoring Vessel



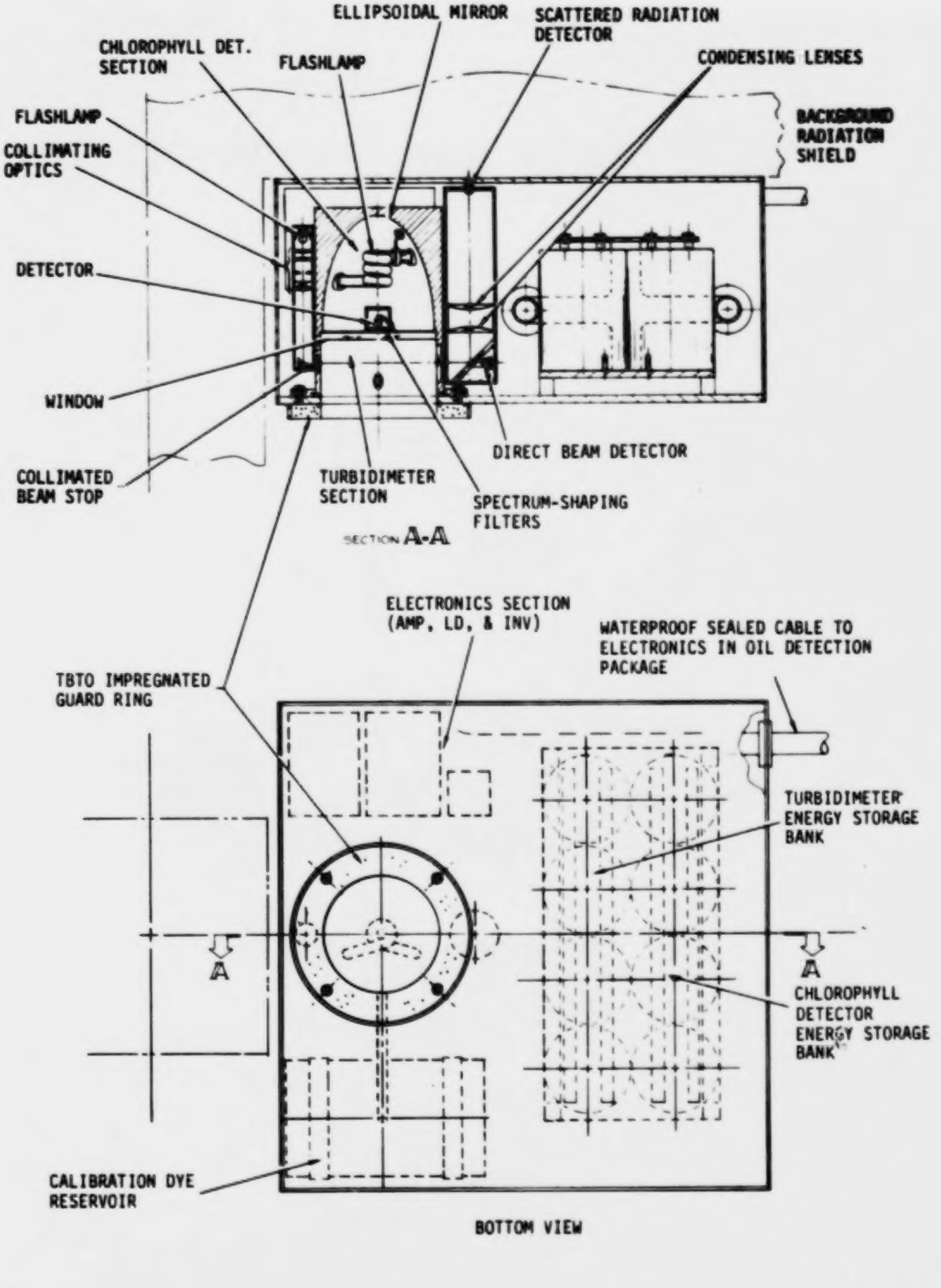
FWD149-10

WATER QUALITY MONITORING MOORED BUOY



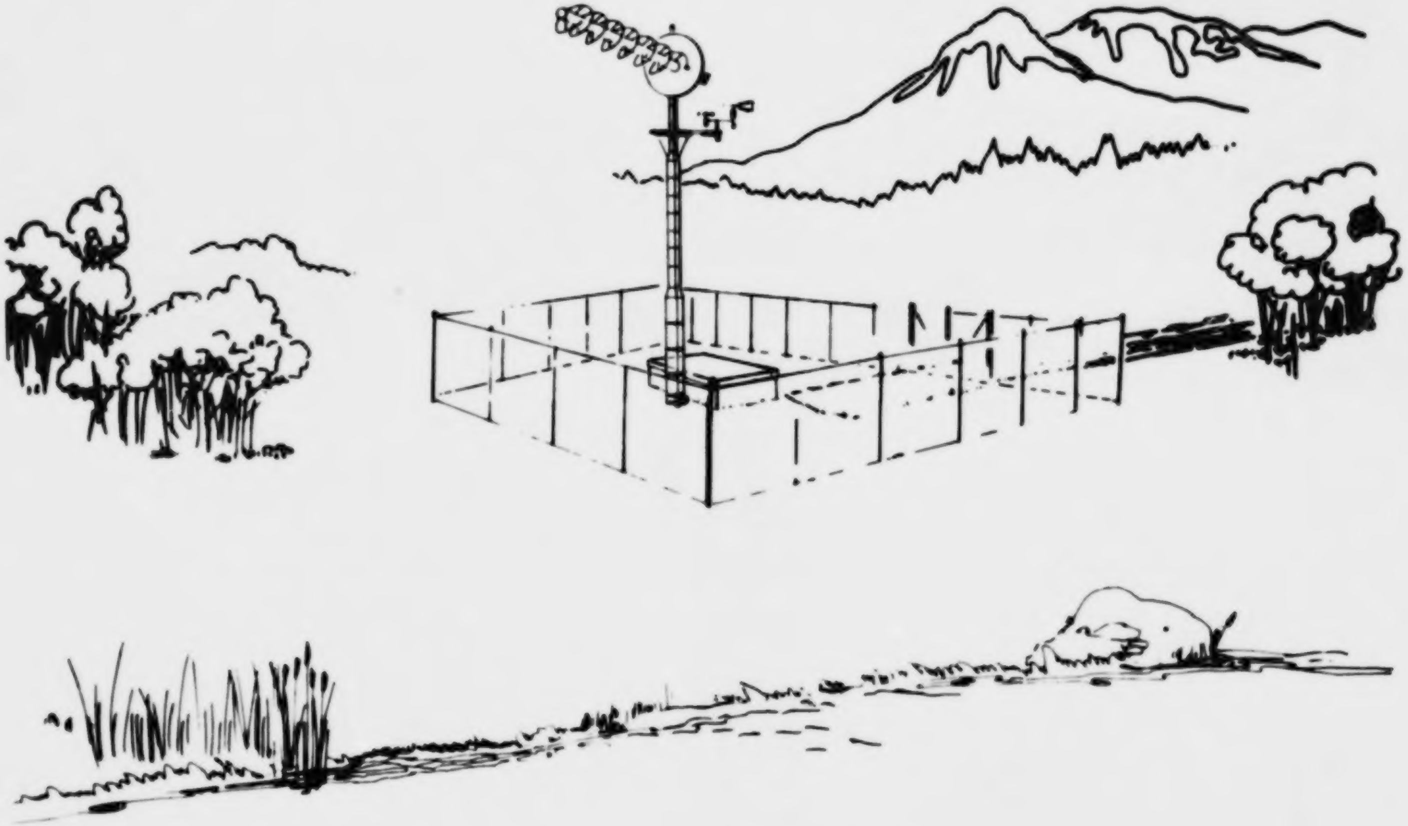
73-8-3538

Chlorophyll Detection and Turbidimeter Package

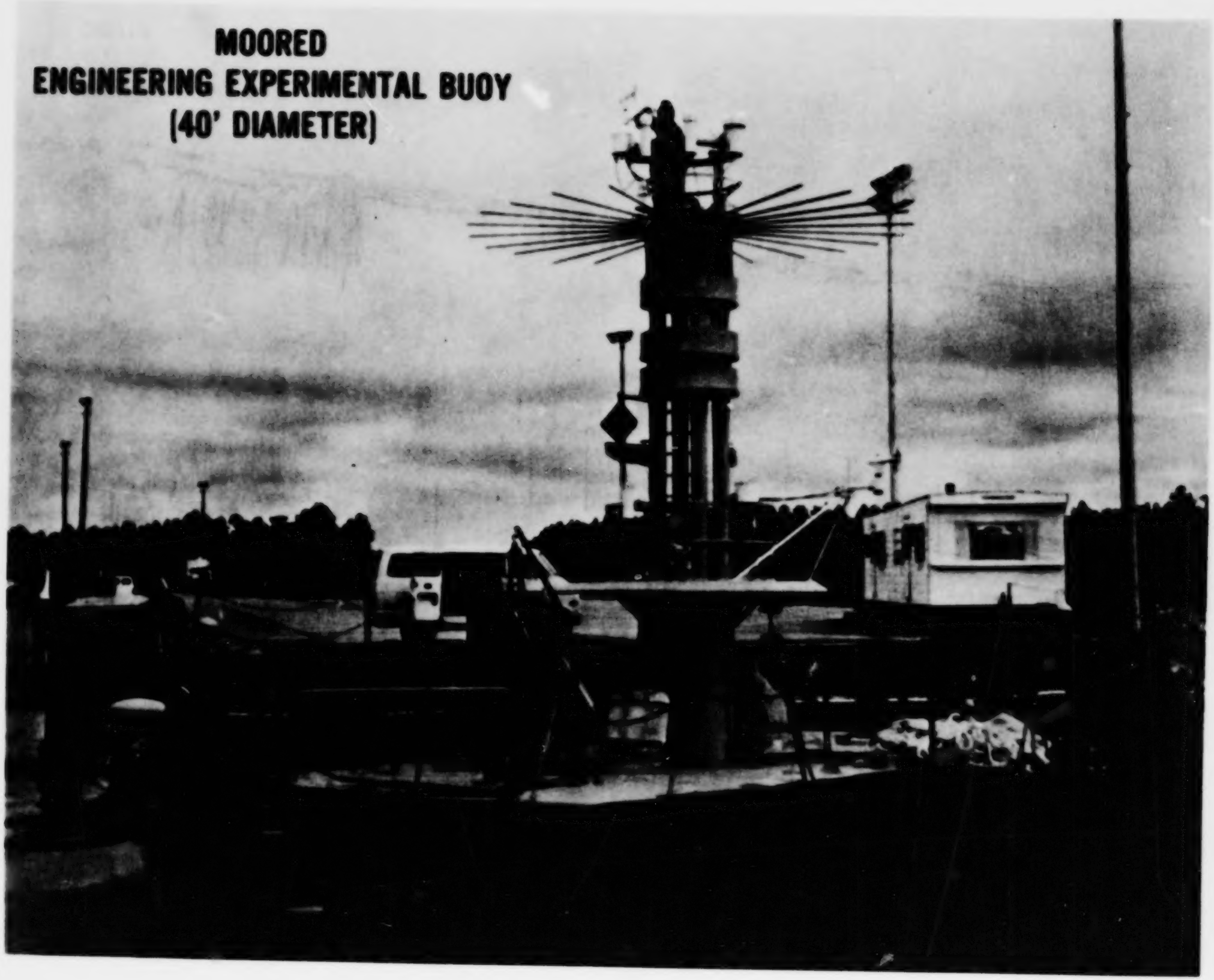

ELLIPSOIDAL MIRROR
SCATTERED RADIATION DETECTOR
CHLOROPHYLL DET. SECTION
FLASHLAMP
CONDENSING LENSES
FLASHLAMP
BACKGROUND RADIATION SHIELD
COLLIMATING OPTICS
DETECTOR
WINDOW
COLLIMATED BEAM STOP
DIRECT BEAM DETECTOR
TURBIDIMETER SECTION
SPECTRUM-SHAPING FILTERS
SECTION A-A
ELECTRONICS SECTION (AMP, LD, & INV)
WATERPROOF SEALED CABLE TO ELECTRONICS IN OIL DETECTION PACKAGE
TBTO IMPREGNATED GUARD RING
TURBIDIMETER ENERGY STORAGE BANK
A
A
CHLOROPHYLL DETECTOR ENERGY STORAGE BANK
CALIBRATION DYE RESERVOIR
BOTTOM VIEW

FWD375-22

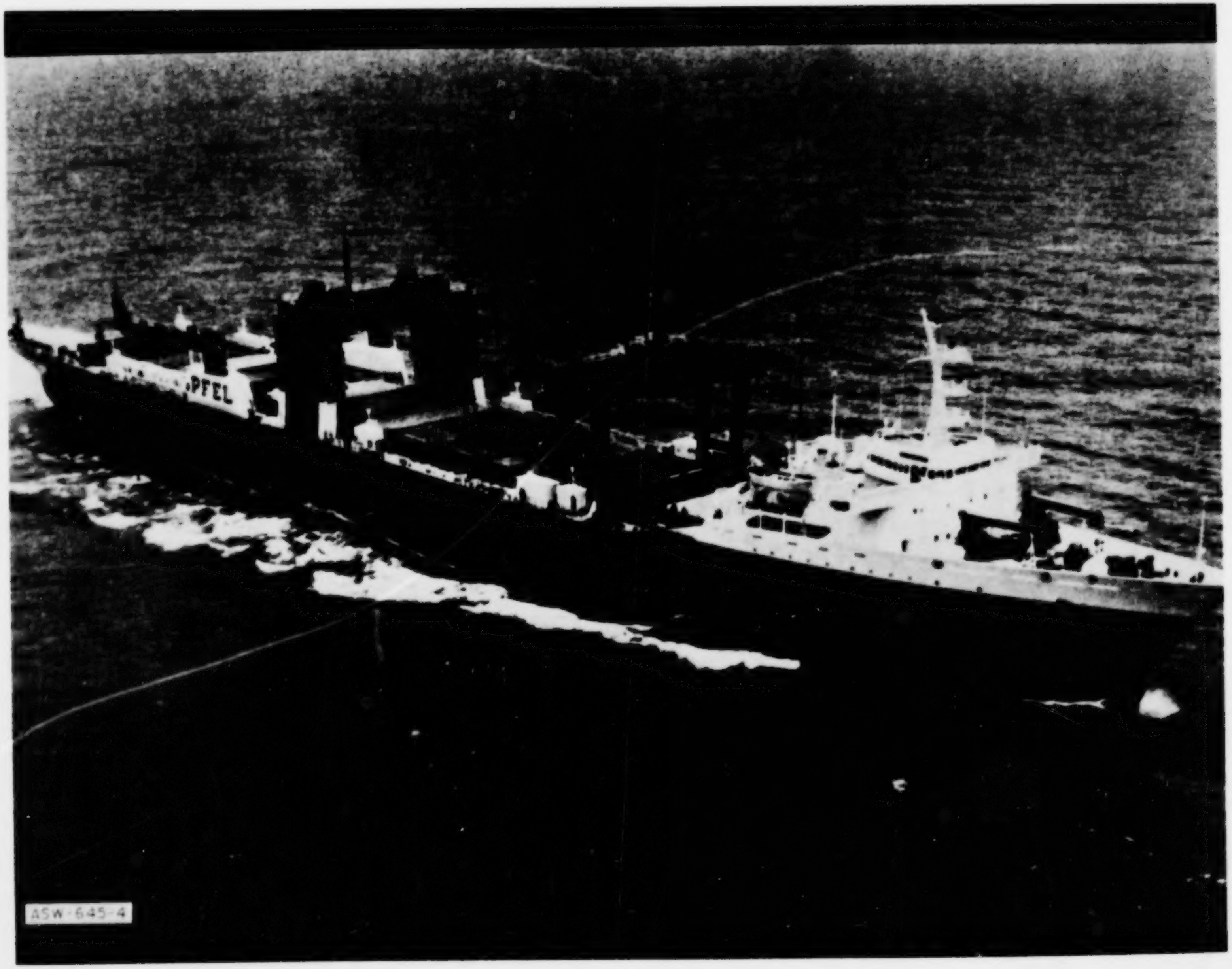
METEOROLOGICAL STATION



0897TM



MOORED
ENGINEERING EXPERIMENTAL BUOY
(40' DIAMETER)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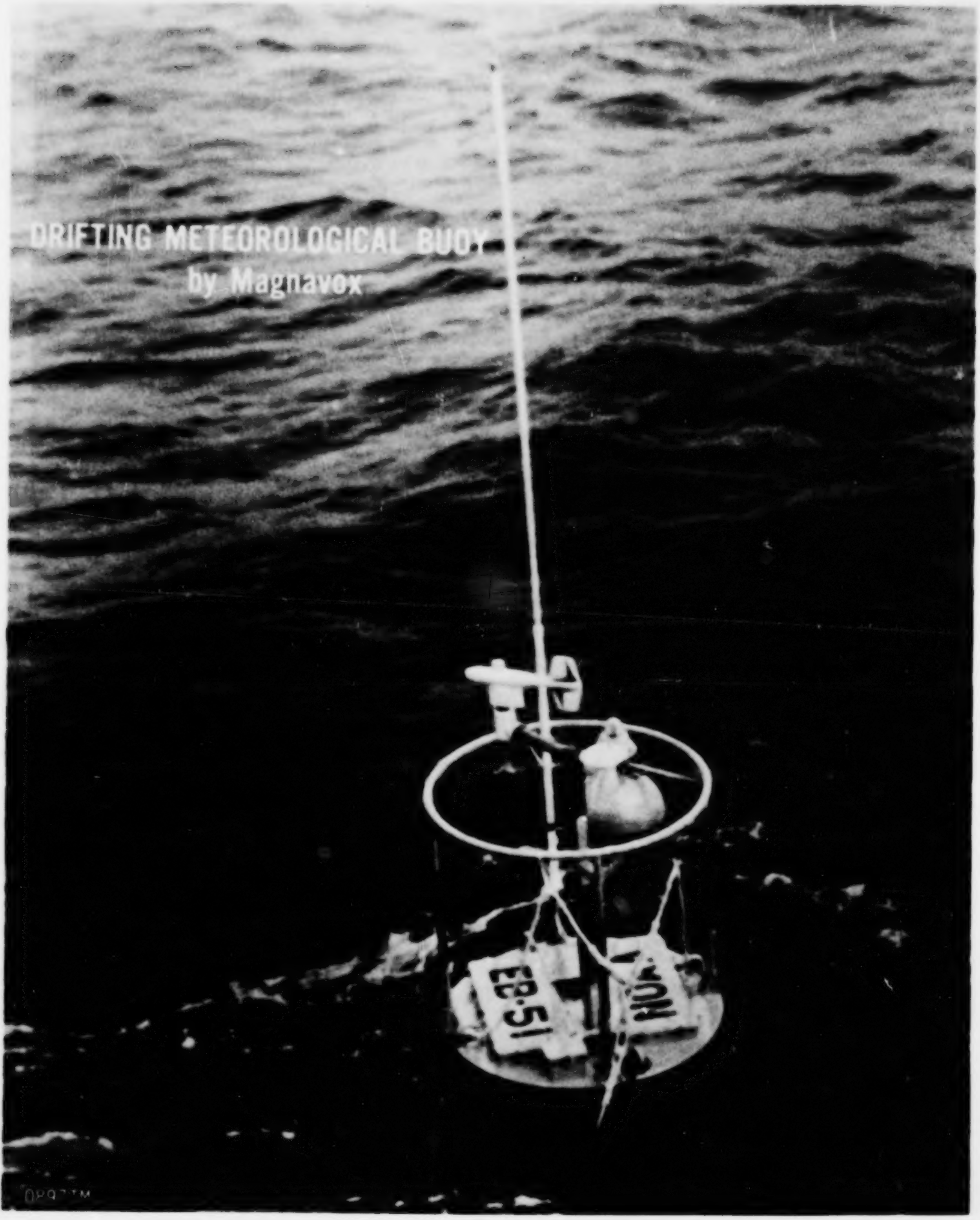
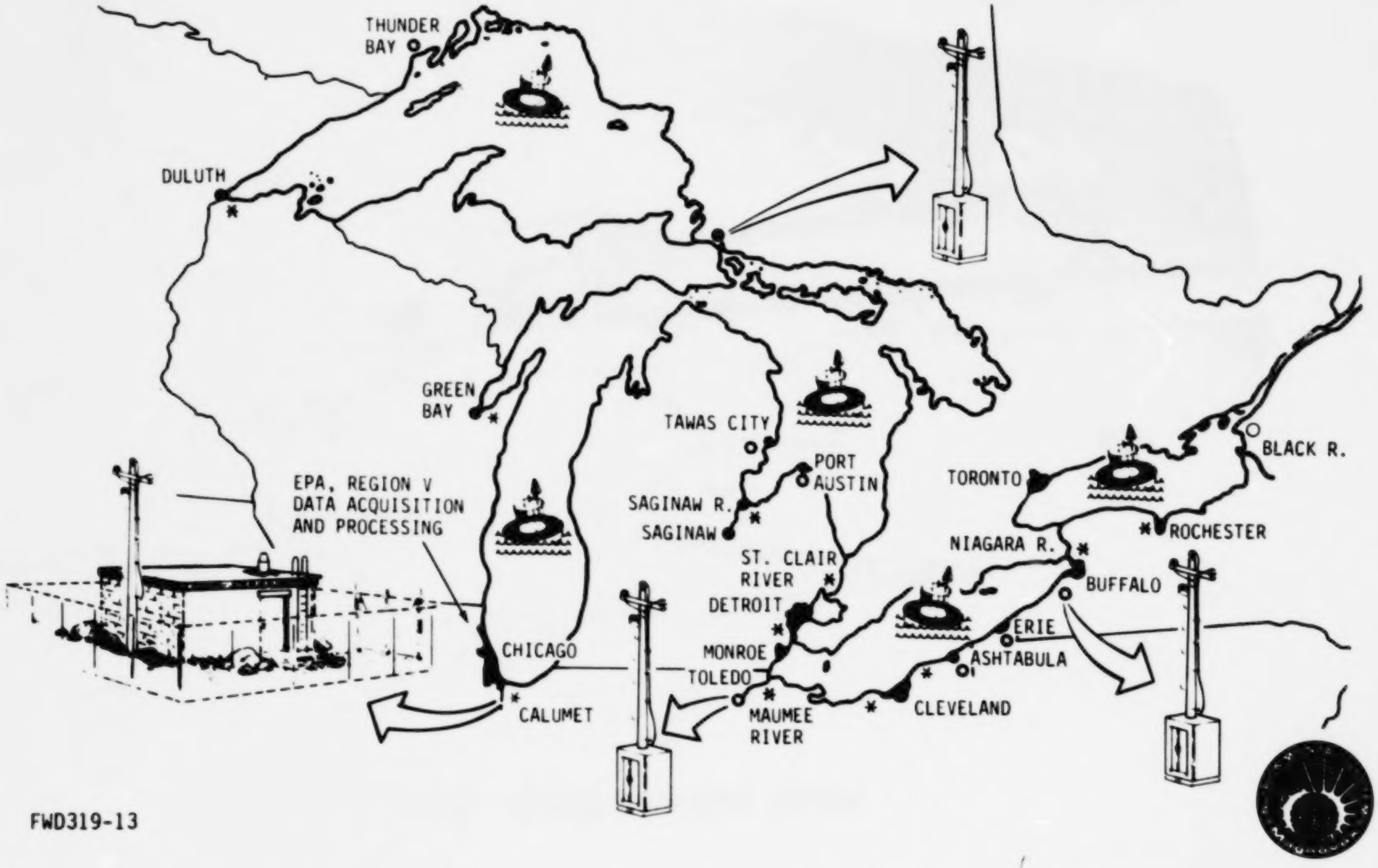
ASW-645-4



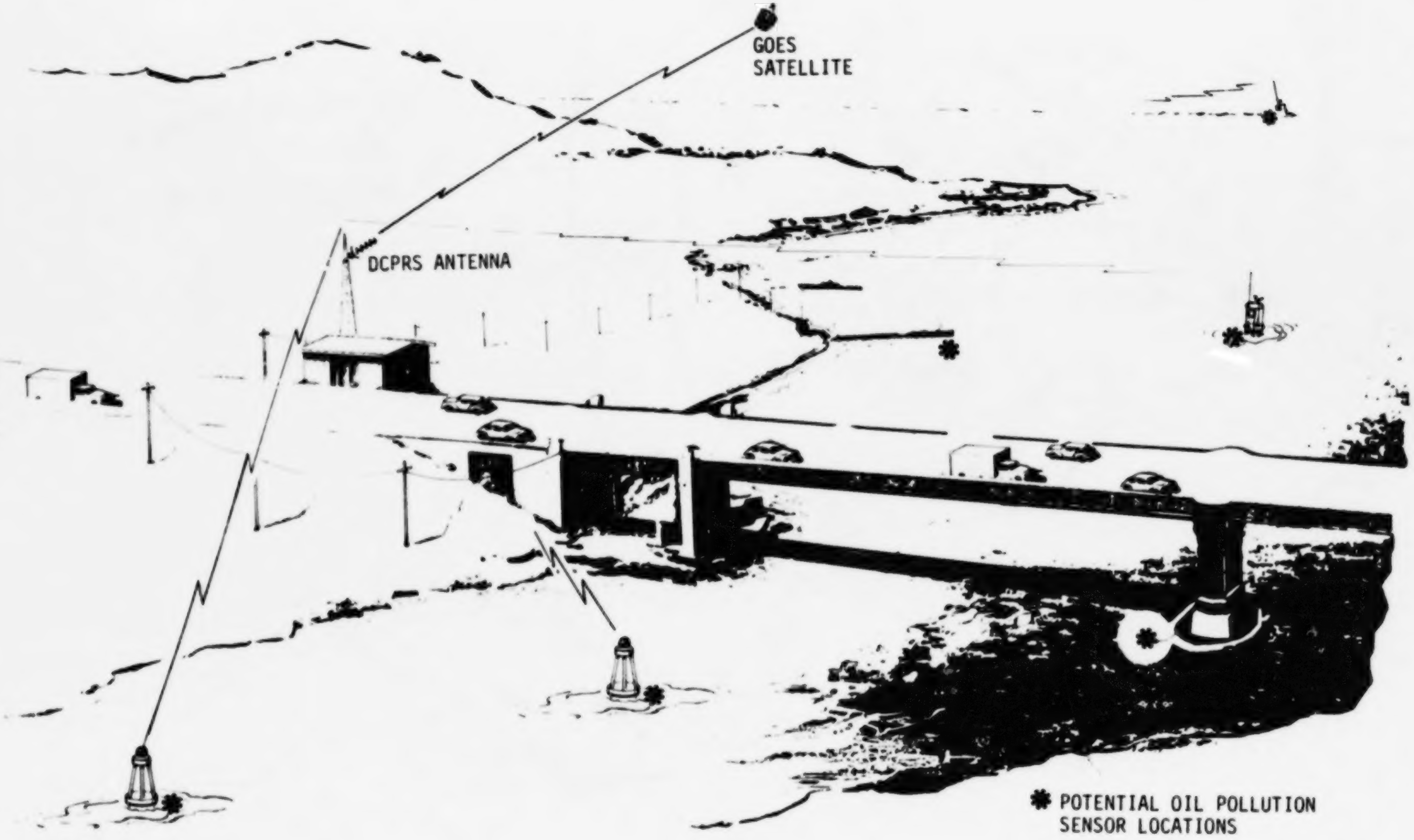
DRIFTING METEOROLOGICAL BUOY
by Magnavox

Great Lakes Environmental Monitoring System

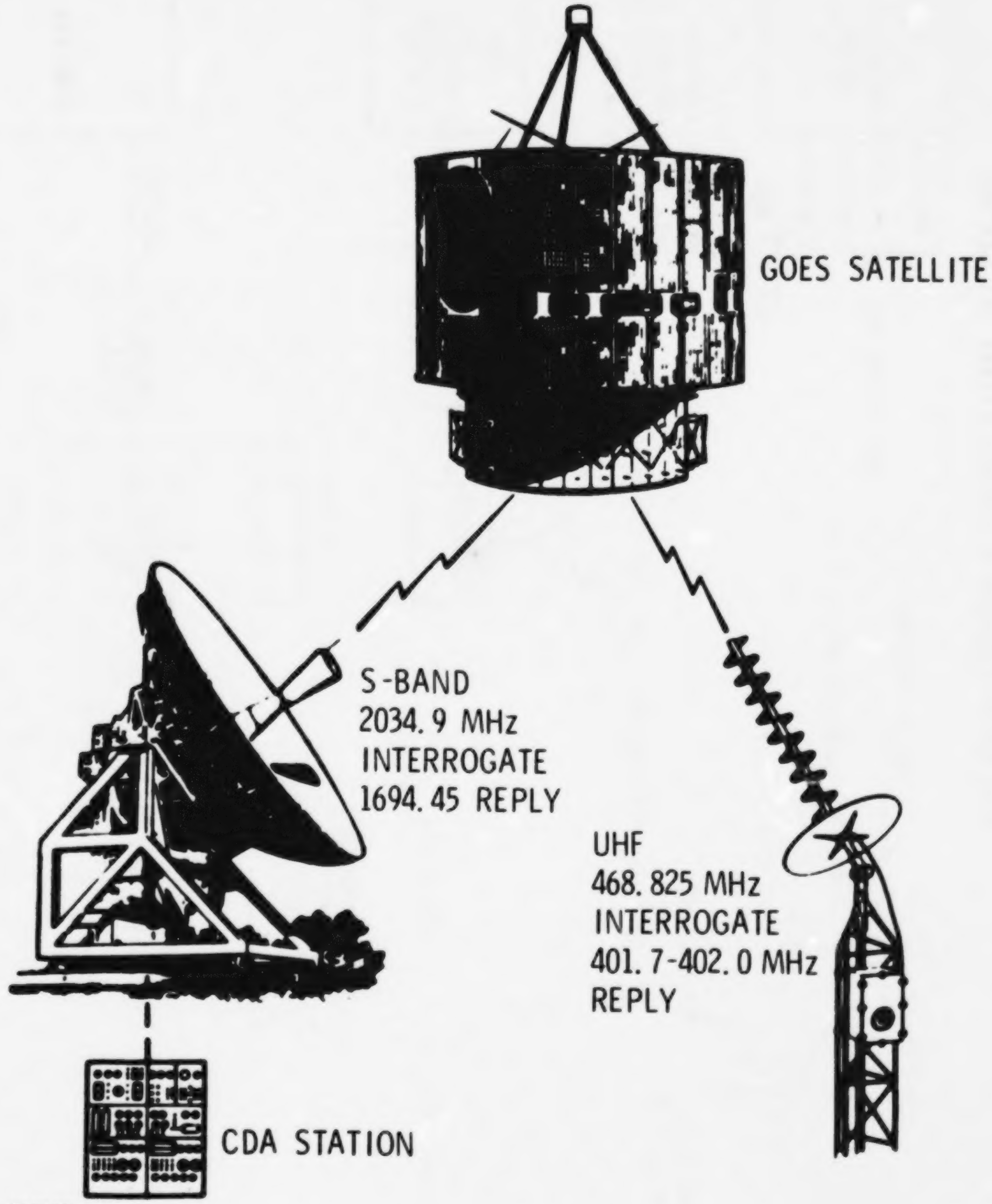


FWD319-13

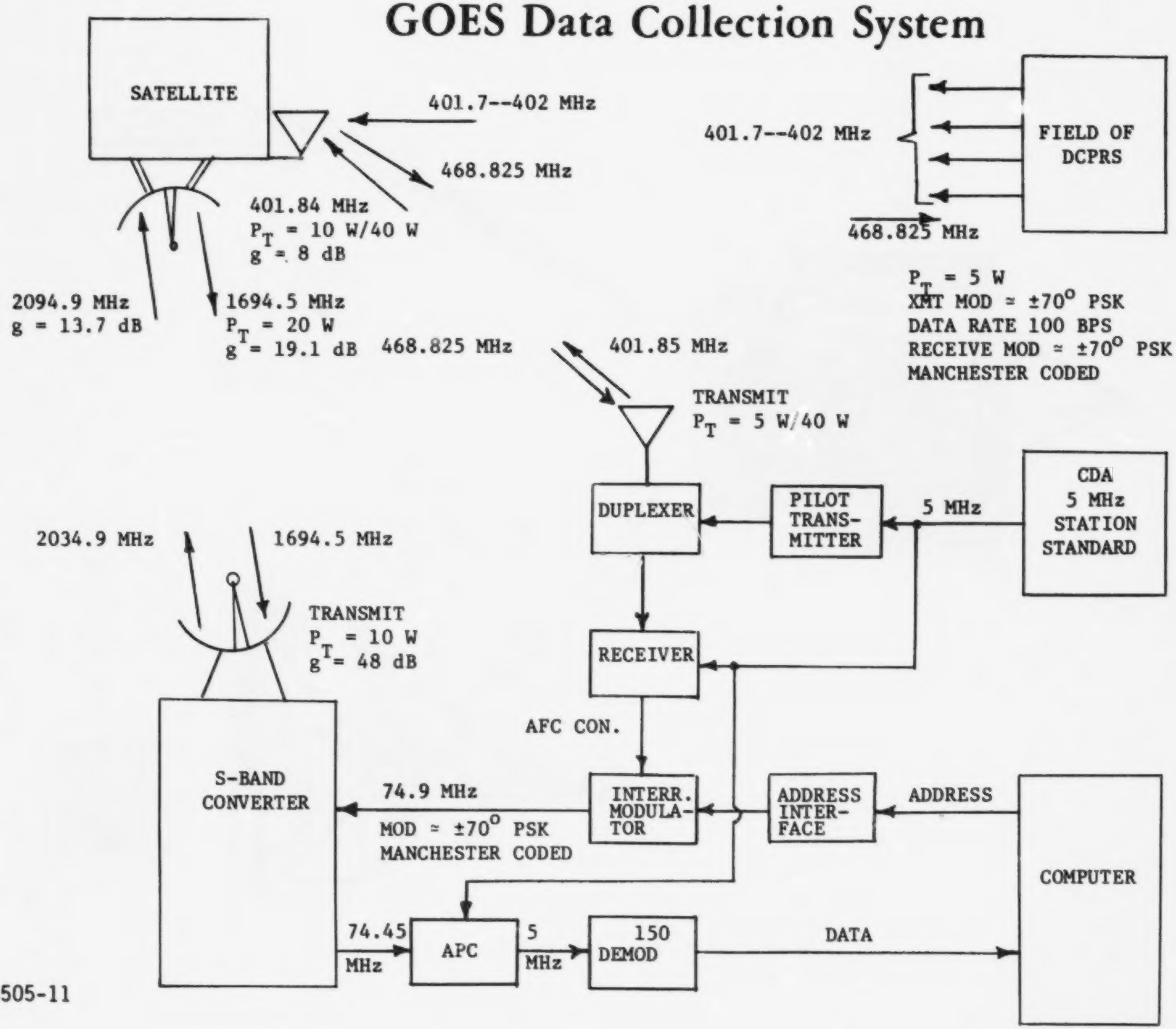
USCG - Oil Spill Surveillance System



Data Collection System Employing Interrogated DCPRS

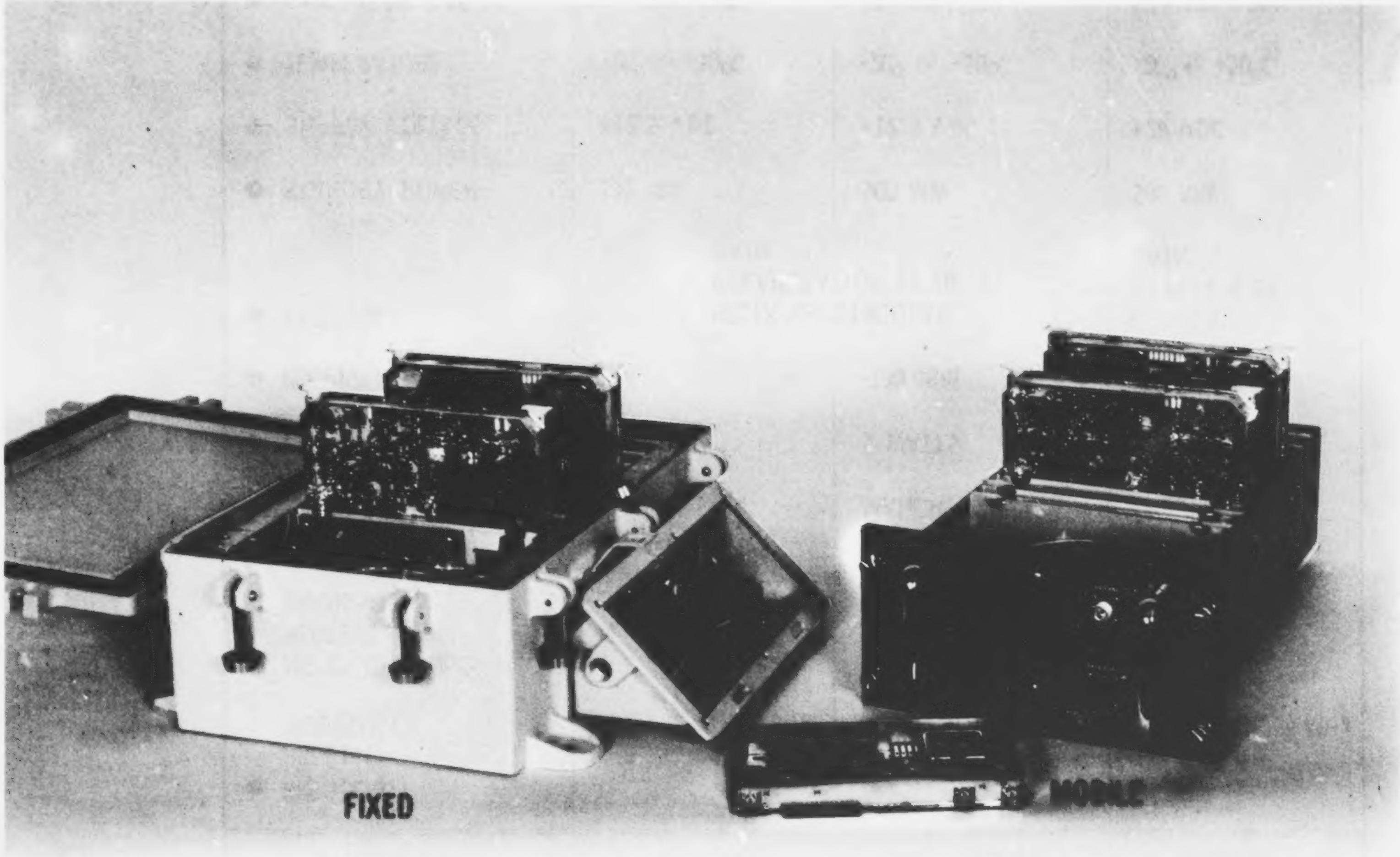


GOES Data Collection System



VG8505-11

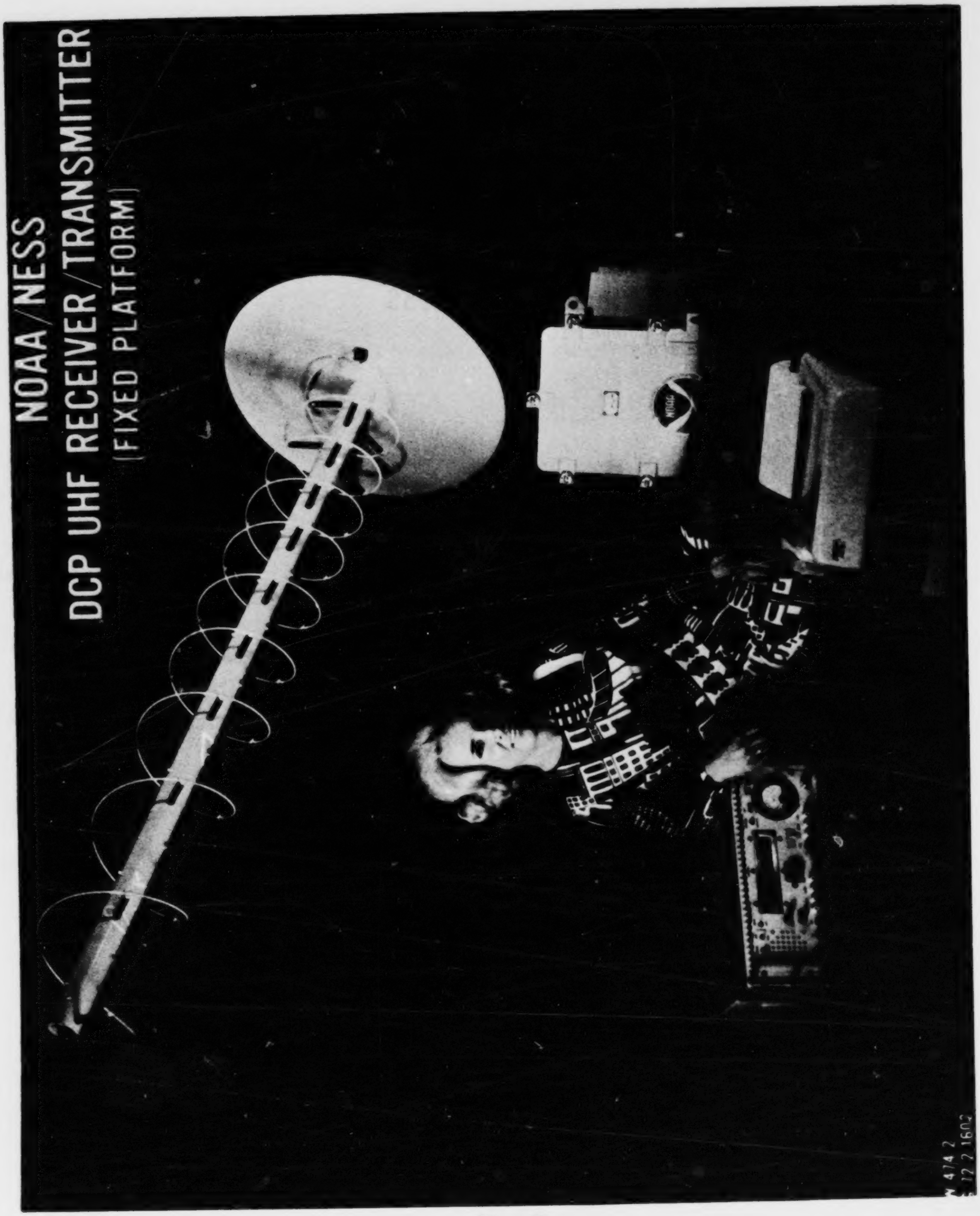
NOAA/NESS DCP RADIOS



DCP Radio Set Specifications Fixed And Mobile

PARAMETER	FIXED LOCATIONS		MOBILE
	SELF TIMED	INTERROGATED	
● FREQUENCY RECEIVE TRANSMIT	 N/A 401. 7 to 401. 85 MHz	 468. 825 MHz 401. 85 to 402. 1 MHz	 468. 825 MHz 401. 7 to 401. 85 MHz
● NO OF CHANNELS RECEIVE TRANSMIT	 N/A 50	 1 150	 1 100
● MODULATION TECHNIQUE	± 70^0 PSK $\overline{\text{M}}$ANCHESTER	± 70^0 PSK $\overline{\text{M}}$ANCHESTER	± 70^0 PSK $\overline{\text{M}}$ANCHESTER
● TRANSMITTED POWER	5 WATTS	5 WATTS	40 WATTS
● RECEIVER SENSITIVITY	N/A	-130 dBm	-135 dBm
● ANTENNA	HELIX RH CIRCULAR POLARIZATION 13 dB GAIN		CONICAL SPIRAL 4 dB GAIN
● STANDBY POWER	132 MW	500 MW	500 MW
● SUPPLY VOLTAGE	+12.5 VDC	+12.5 VDC	+28 VDC
● TEMPERATURE	-20^0 to +50^0C	-20^0 to +50^0C	-20^0 to +50^0C
● SIZE (LESS CASE)	6" x 12" x 18"	6" x 12" x 18"	6" x 12" x 20"
● WEIGHT (LESS CASE)	12 LBS	17 LBS	28 LBS

VG8505-14

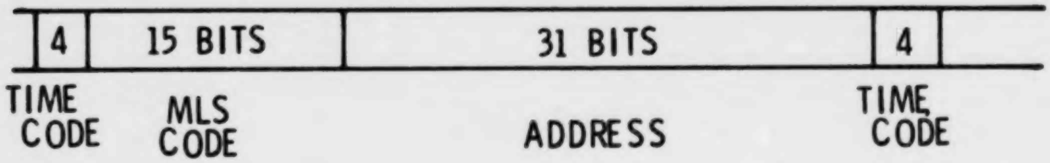


NOAA/NESS

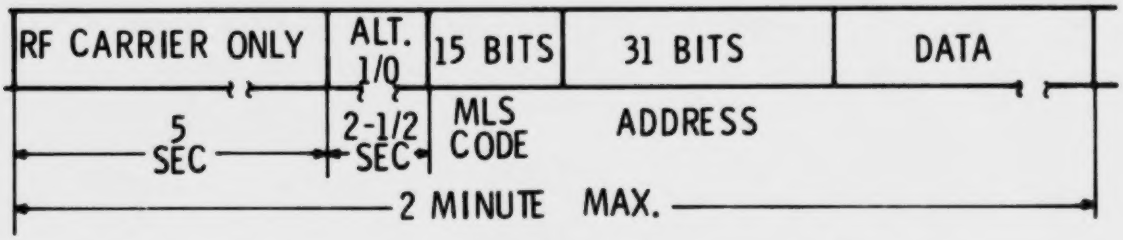
DCP UHF RECEIVER/TRANSMITTER

(FIXED PLATFORM)

INTERROGATION DCPRS COMMAND FORMAT



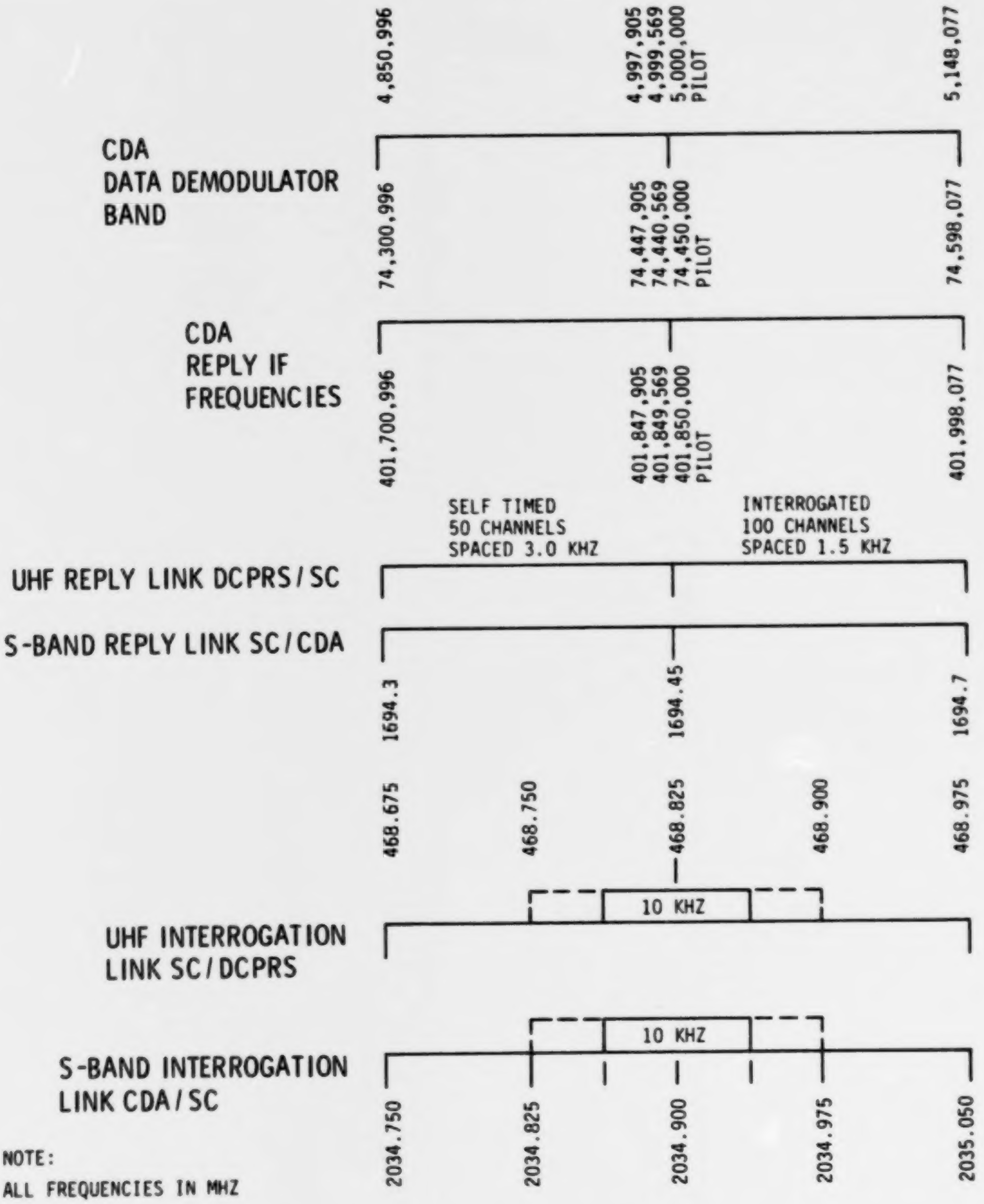
REPLY MESSAGE FORMAT



UNLESS REINTERROGATED
FOR ANOTHER 2 MINUTE
PERIOD.

VG8505-8

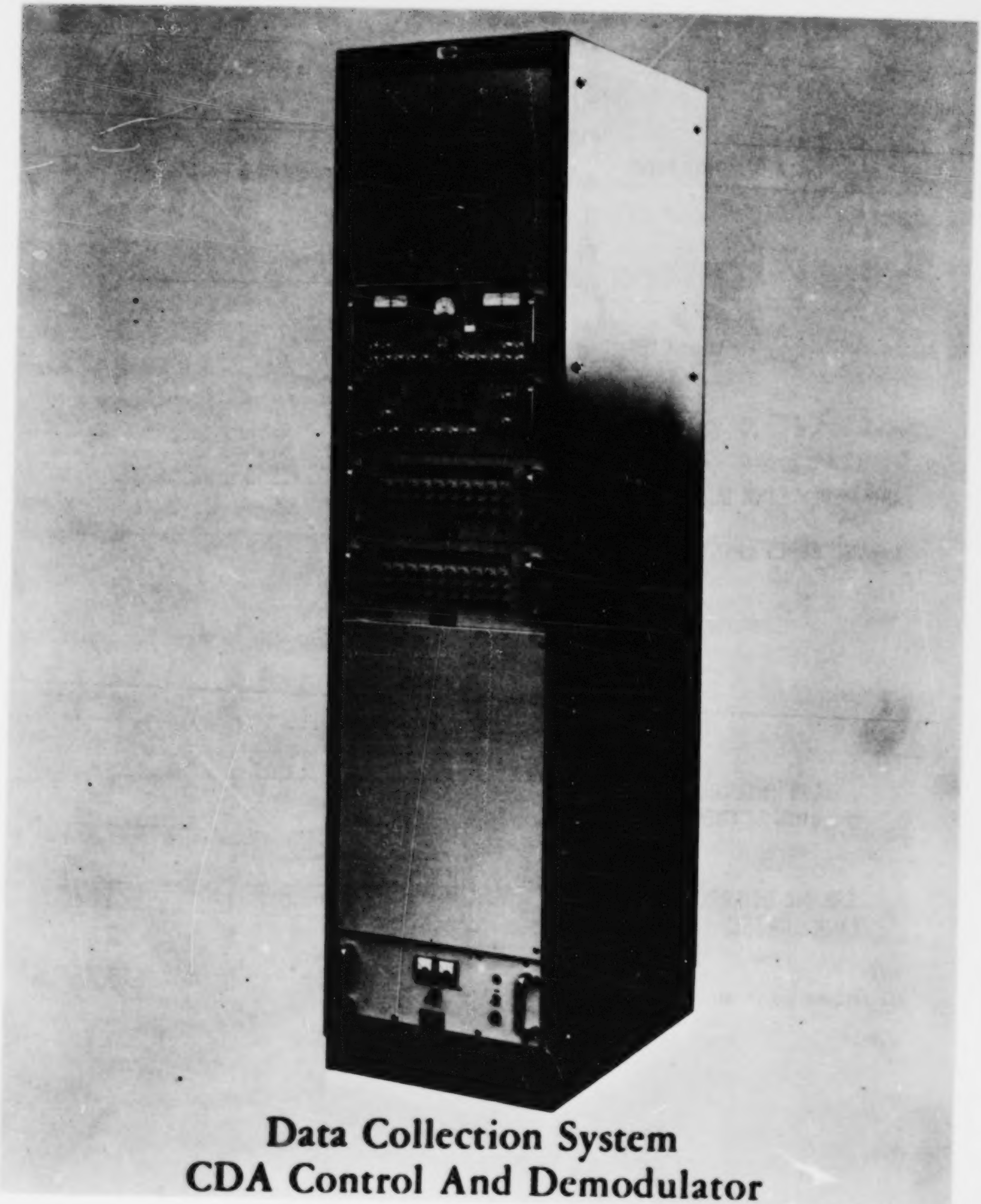
DCPRS/SC/CDA Detailed Frequency Plan



NOTE:

ALL FREQUENCIES IN MHZ

219-14



Data Collection System
CDA Control And Demodulator

CDA GROUND STATION DATA COLLECTION SUBSYSTEM

FEATURE

- Simultaneous reception of 20 reply channels
- Automatic acquisition and phase lock tracking of reply channels
- Matched filter data detection
- Automatic acquisition and phase tracking of pilot carrier (referenced to CDA 5 MHz standard)
- Pilot carrier synthesis referenced to CDA 5 MHz standard
- AFC Control of Interrogate Channel frequency
- Multiplex of reply data at 2400 bps for transmission on unconditioned lines
- Automatic generation of address request
- Self-contained built-in test equipment
- Ease of maintenance through plug-in modules

DESIGN FLEXIBILITY

- Expandable to 150 channels
- Expandable to provide Bit Error Rate testing
- Adaptable to on-site computer control

ES64451-1

MATERIALS VS METHODS

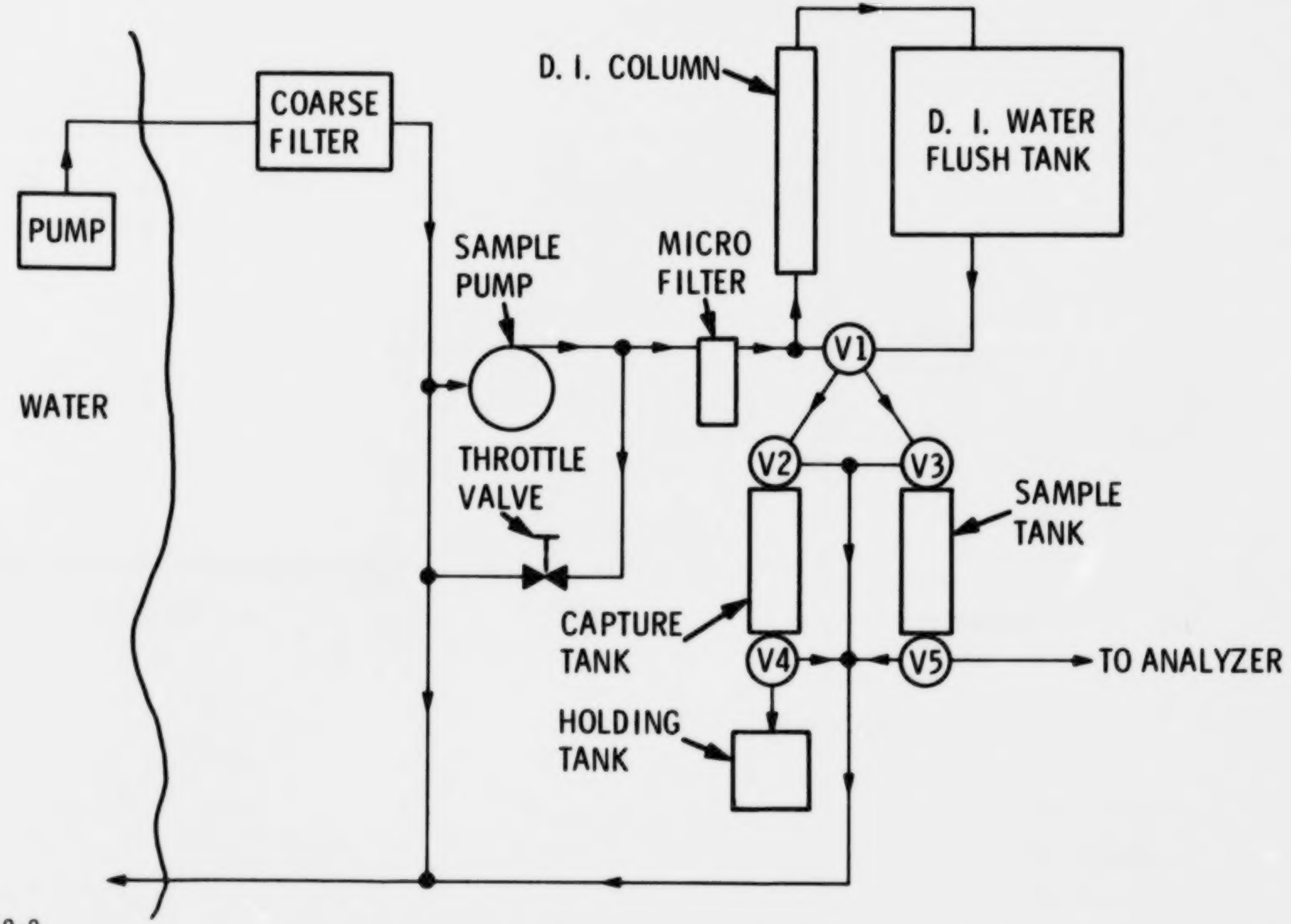
METHOD MATERIAL	ENERGY-DISPERSIVE X-RAY	ECD GAS CHROMATOGRAPHY	AA SPECTROPHOTOMETRY	FE SPECTROPHOTOMETRY	COLORIMETRY	PROBE MEASURABLE	FLUORESCENCE (UV)	SCINTILLATION COUNTER	ANODIC STRIPPING POLAROGRAPHY	MICROSCOPY
PHENOL					●					
T-DDT		●								
DIELDRIN		●								
HEPTACHLOR		●								
METHOXYCHLOR		●								
LINDANE		●								
ALDRIN		●								
ENDRIN		●								
IRON	●		●	●	●					
MERCURY	●		●							
ARSENIC			●		●					
CADMIUM	●		●	●					●	
ZINC	●		●	●					●	
PHOSPHORUS	●				●					
CHROMIUM	●		●	●	●					
SELENIUM			●		●					
COPPER	●		●	●					●	
LEAD	●		●	●					●	
NICKEL	●		●	●	●					
BARIUM	●		●	●						
MICROBIOLOGY										●
DISSOLVED OXYGEN						●				
DISSOLVED SOLIDS						●				
p^H						●				
RADIOACTIVITY								●		
TEMPERATURE						●				
SUSPENDED SOLIDS						●				
OIL							●			
AMMONIA					●	●				
CHLORIDE					●	●				
CYANIDE					●	●				
FLUORIDE					●	●				
SULFATE					●					

SPECIFIC

GENERAL

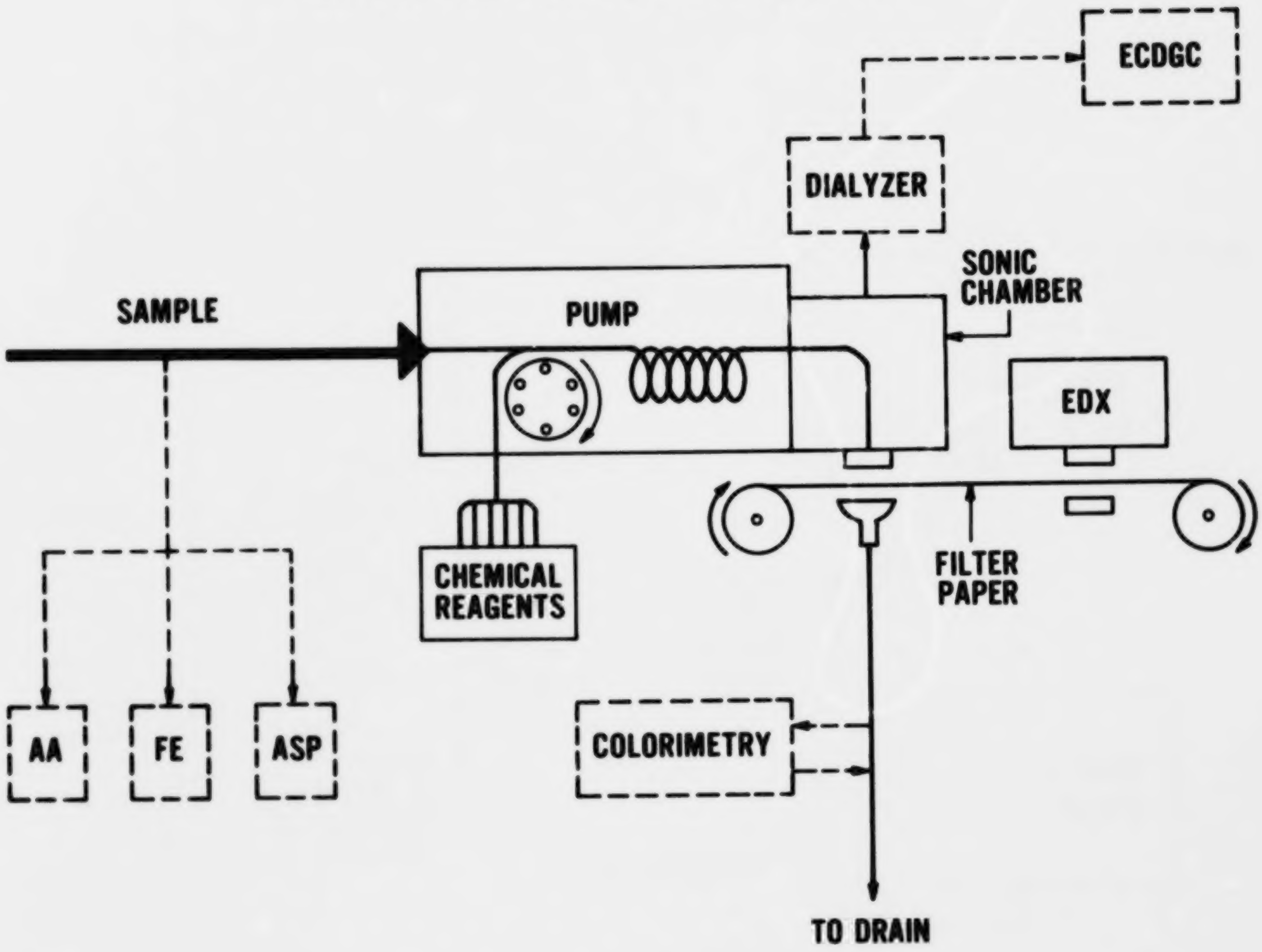
FWD319-1

SAMPLE ACQUISITION



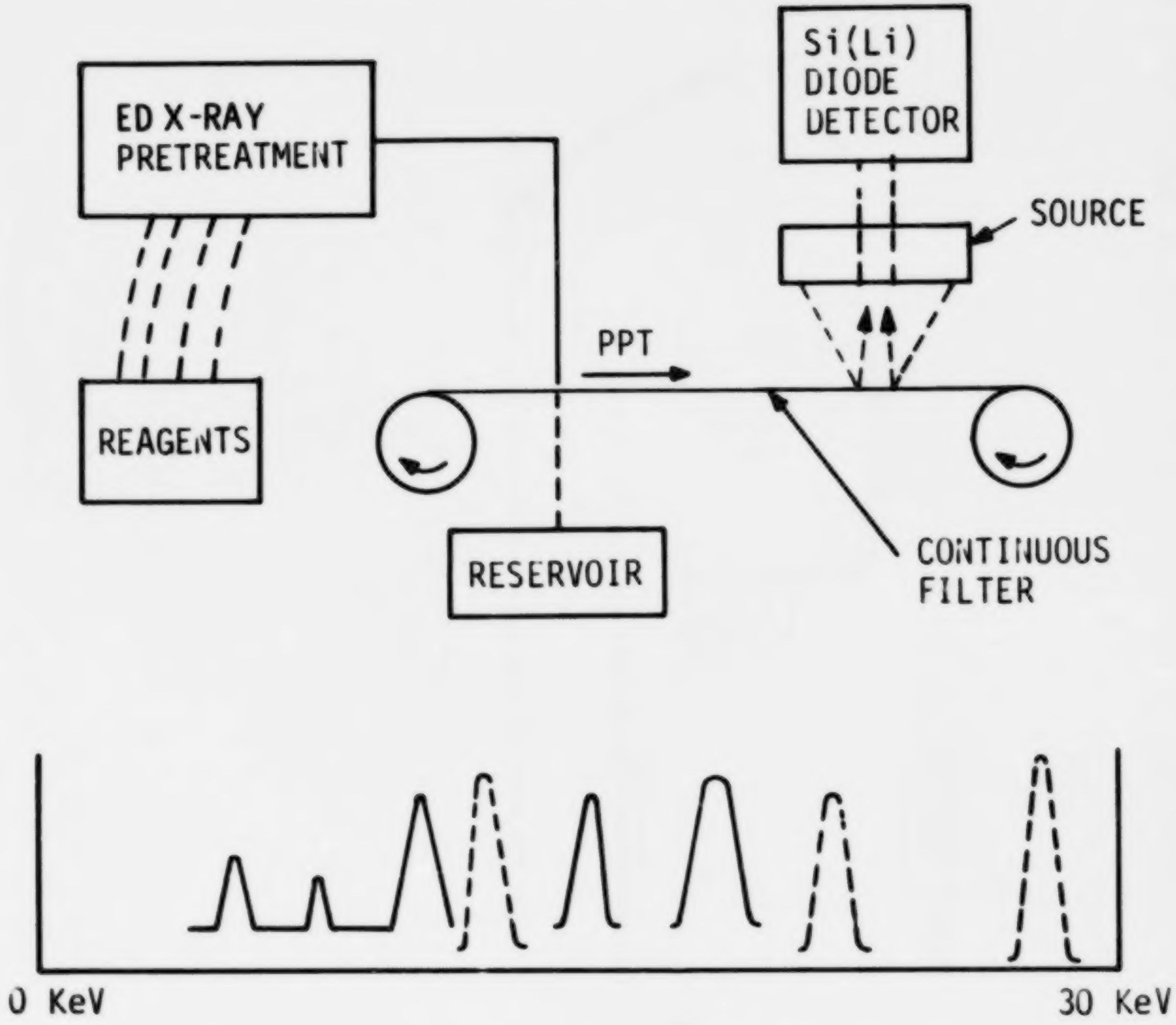
FWD319-9

SAMPLE PRETREATMENT



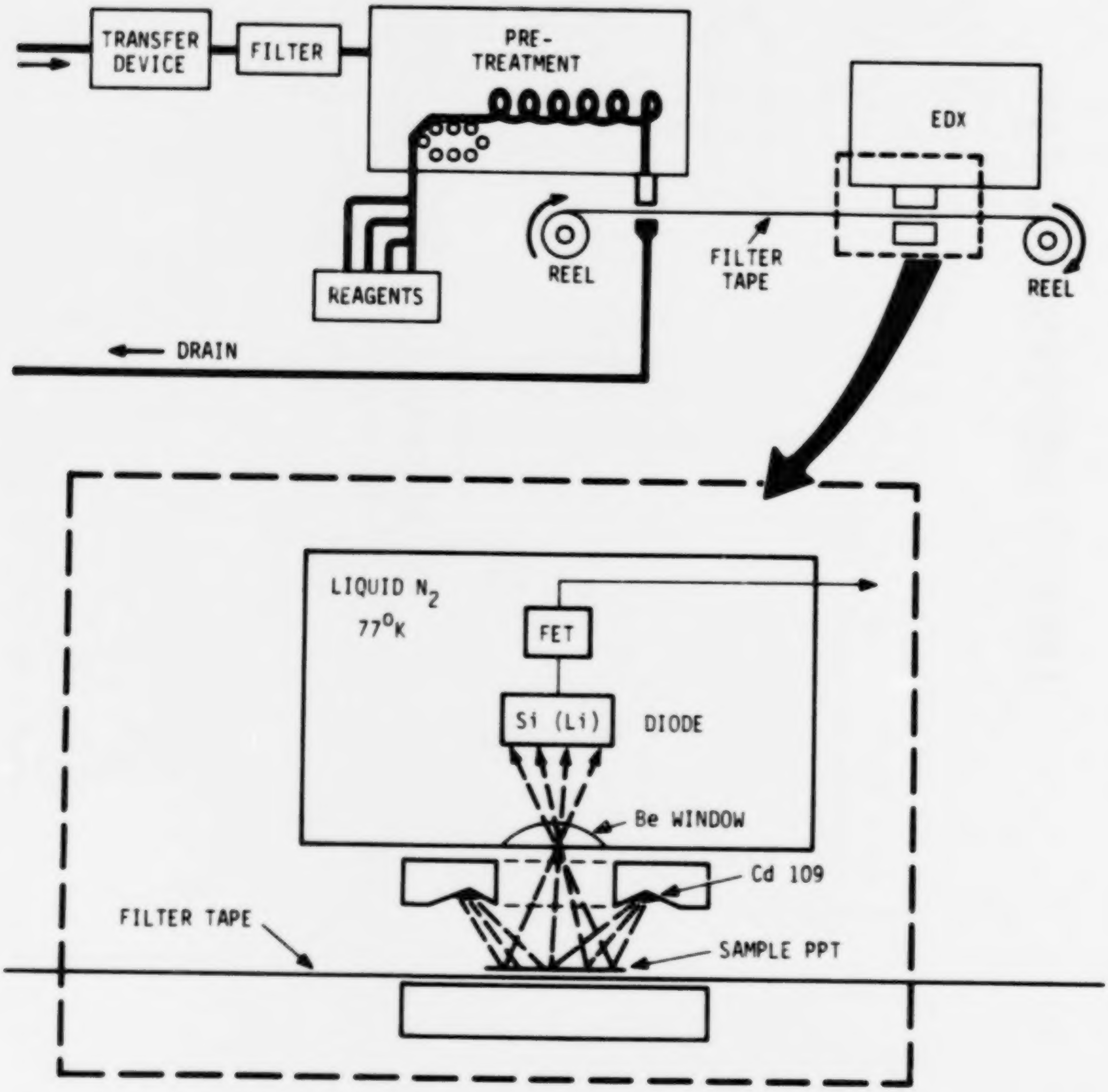
FWD460-5

ENERGY-DISPERSIVE X-RAY

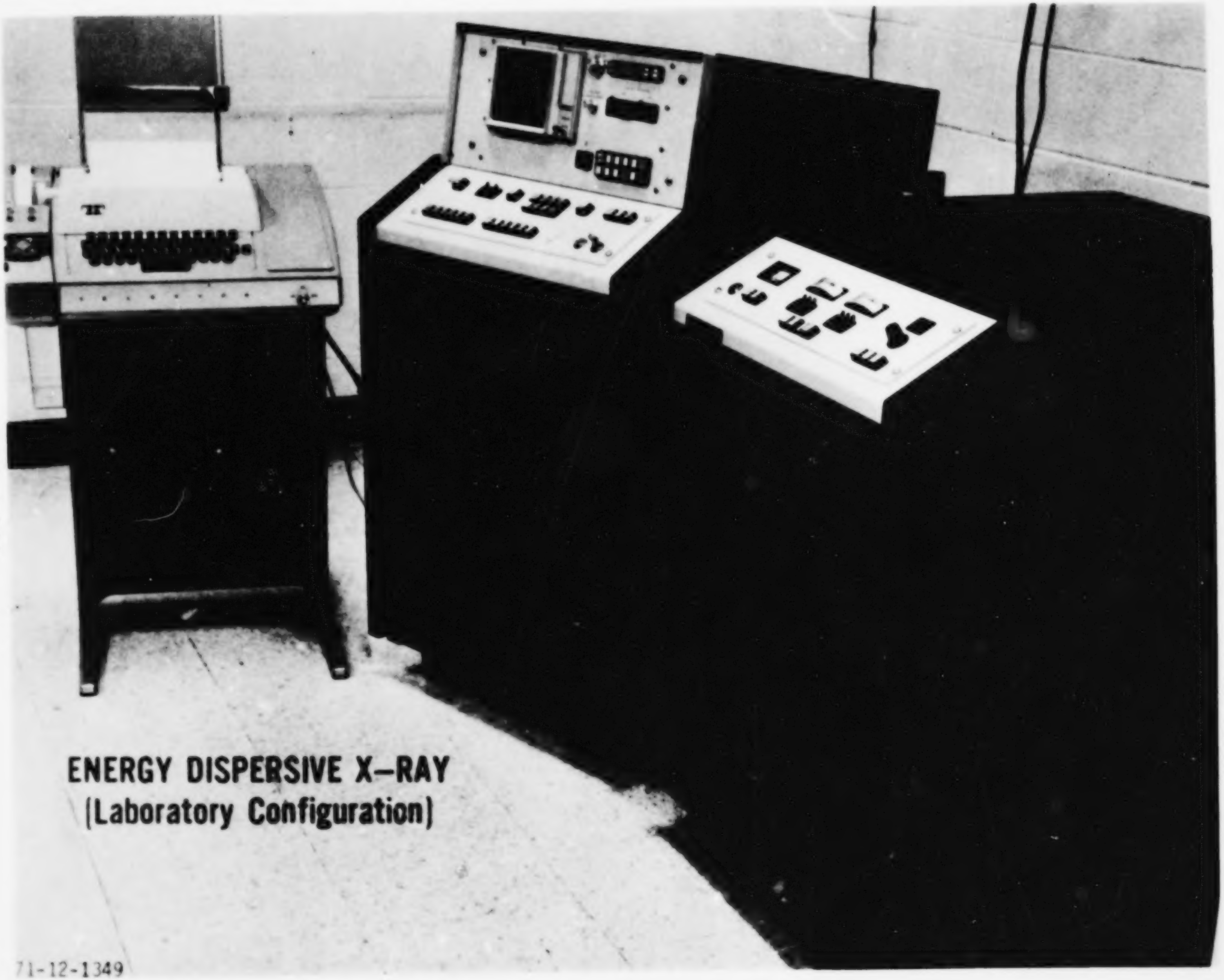


FWD319-4

AUTOMATED ENERGY DISPERSIVE X-RAY SYSTEM



FWD170-3



ENERGY DISPERSIVE X-RAY
(Laboratory Configuration)

71-12-1349

SESSION VII

SATELLITE ENVIRONMENTAL MONITORING APPLICATIONS

CHAIRMAN

MR. JOHN D. KOUTSANDREAS

OFFICE OF MONITORING SYSTEMS, OR&D

SKYLAB APPLICATION TO ENVIRONMENTAL MONITORING

by:

Victor S. Whitehead
NASA Johnson Space Center

Abstract

The Skylab Earth Resources Experiment Package (EREP) provides a view of the Earth with relatively high spacial and spectral resolution through the visible and parts of the near and thermal infrared regions of the spectrum. Although the design of Skylab restricts its use as an operational platform for environmental monitoring, observations taken with the Earth Resources Experiment Package are being used in some research studies directly related to environmental monitoring and in a larger number that have an indirect bearing on environmental quality in general. There are 148 experiments in progress using the EREP facility. These include such varied areas of investigation as: vegetative characteristics such as crop vigor, land use and regional planning, sea surface characteristics and circulation, atmospheric contamination, and water pollution, all these are factors to be considered in environmental quality. These experiments will not only provide increased knowledge of the environment but will also provide guidance on design requirements for future observation systems. EREP observations are taken at the times and places required to support these 148 experiments. The data collected, however, is placed immediately in the public domain, available to any investigator.

The systems within the EREP that are being used in environmental monitoring are:

Multispectral Photographic Facility S190A
Earth Terrain Camera S190B
Skylab Spectrometer S191
Multispectral Scanner S192

The capabilities and restrictions of these systems, along with a description of the quality of data they are providing, is presented in the text.

SKYLAB APPLICATION TO ENVIRONMENTAL MONITORING

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The Skylab was launched and inserted into a 234 n. mi. circular orbit at 50° inclination on May 14, 1973. Eleven days later, the spacecraft was occupied by a three man crew to begin the first of three planned extended periods of scientific observations from space. The scientific objectives of Skylab are:

- To study man - Determine physiology conditioning and performance capability in real time in zero-gravity environment for long-duration space flight.
- To study the sun - Synoptic survey and study of special phenomena on the solar disk in x-ray, ultraviolet, and visible spectral wavelengths.
- To study space technology - Evaluate coating degradation, spacecraft contamination, manufacturing and repair techniques, and manned maneuvering units.
- To study the earth - Synoptic survey of selected areas on the earth in visible, infrared, and microwave spectral wavelengths.

This last objective will be the only one discussed here. It should be noted that the facility, crew-time, and some consumables are shared among objectives. Scheduling of experiment performance then is a critical effort in achieving optimum use of the Skylab and, at times, can become quite complex when individual experiment requirements conflict with each other.

To observe the earth, the crew has as its tool, the Earth Resources Experiment Package (EREP)(Fig. 1), a cluster of five instruments systems designed to aid the scientific community in determining the spectral and spatial resolution required for earth resources applications, the utility of microwave in earth resources surveys, and the effects of atmosphere in optical and electronic data analysis.

Of the five EREP systems three

1) The multispectral photographic facility with earth terrain camera,

2) The infrared spectrometers system, and

3) The multispectral scanner

produce data which are directly applicable to some areas of environmental monitoring.

The other two systems,

4) Microwave radiometer-scatterometer and altimeter, and

5) The L-band radiometer

are oriented more to test of the feasibility of acquiring microwave data from space than to direct application of the resulting data. The discussion here is directed to the utility of the data collected by the first three systems. Only a cursory description of the individual systems and integrated Skylab system is given here. Those interested in a more detailed description are referred to the EREP Users Handbook, "NASA Document S-72-831-V and the Skylab EREP Investigators Data Book."

Multispectral Photographic Facility (S190A) with Earth Terrain Camera (S190B)

The S190A provides radiometrically and metrically accurate images of ground radiance for a wide range of user-oriented studies. It consists of a band of six calibrated boresighted 6" focal length cameras capable of handling a variety of film-filter combinations. Output format is 70 m square. The field of view of 21.2° provides an 88 n. mi. by 88 n. mi. view from 234 n. mi. altitude. Forward overlap of up to 90% is possible. All housekeeping data is recorded. The standard load for S190A and its characteristics are:

Film	Filter	Wavelength Micrometers	Resolution Ft.
PAN-X B&W (SO022)	AA	0.5 - 0.6	99
PAN-X B&W (SO022)	BB	0.6 - 0.7	91
IR B&W (EK2424)	CC	0.7 - 0.8	223
IR B&W (EK2424)	DD	0.8 - 0.9	223
IR COLOR (EK2443)	EE	0.5 - 0.88	223
AERIAL COLOR (SO356)	FF	0.4 - 0.7	78

The S190B provides high resolution photography in support of other EREP sensors and user-oriented studies. It is compensated for spacecraft motion and can provide up to 85% forward overlap. The focal length is 18-inches providing ground coverage of 59 n. mi. square. The film format is 4.5 inches square. Film and filters available for use in S190B, and their characteristics, are:

Film	Filter	Wavelength Micrometers	Resolution Ft.
AERIAL COLOR (S0242)	None	0.4 - 0.7	60
AERIAL B&W (EK3414)	W-12	0.5 - 0.7	40-60
AEROCHROME IR, COLOR (EK3443)	W-12	0.5 - 0.88	150

The Infrared Spectrometer System (S191)

The Infrared Spectrometer System with Viewfinder tracker, more appropriately called the Skylab Spectrometer, provides quantitative determination of the effects of atmospheric attenuation upon radiation from surface features over a broad spectral range thereby providing inputs into correction for these effects. This instrument consists of a filter wheel spectrometer that spectrally scans the radiation entering its aperture from 0.4 um to 2.5 um and from 6.6 um to 16.0 um, once each second and a viewfinder tracker system, with zoom magnification from 2.25 to 22.5, that looks in same direction as the spectrometer and allows the astronaut to find, track and photograph for record, the site the spectrometer views. The system has internal calibration sources that can be inserted into the field of view on command. The spot size on the surface is 1/4 mi. diameter. The spectral resolution of the system is of the order of 2 or 3% of the wavelength at any wavelength.

The tracker and spectrometer is gimbaled to view 45° to the front 10° to the rear and 20° to either side of track.

Multispectral Scanner (S192)

The S192 scanner provides radiance values simultaneous in 13 bands in the visible, near IR, and thermal IR portions of the Spectrum. Each channel is calibrated 100 times each second. It has a conical scan with a radius of 22.6 n. mi. The instantaneous field of view is 260 feet at the ground (.182 milliradians). The swath width on the ground is 37 n. mi. The bands with asterisks listed below are sampled 1240 times per scan line the ramainder at 2480 times per scan line. There are 94.79 scan lines per second. Design absolute accuracy of the system in the visible and near IR was 5%, in the thermal IR 1.5°K.

The spectral bands covered are:

Band	Coverage, Micrometers
1*	0.41 to 0.46
2*	.46 to .51
3	.52 to .56
4	.56 to .61
5	.62 to .67
6	.68 to .76
7	.78 to .88
8*	.98 to 1.08
9*	1.09 to 1.19
10*	1.20 to 1.30
11	1.55 to 1.75
12	2.10 to 2.35
13*	10.20 to 12.5

There are restrictions due to the design and operational requirements of Skylab that limit its EREP data gathering ability. The orbital inclination restricts its nadir viewing capability to ± 50° latitude. The orbit was also planned to provide repetitive coverage, at five day intervals of defined ground tracks; this, coupled with the high resolution - narrow field of view of the sensors leaves, on a nominal mission, significant gaps between tracks that cannot be covered. The Skylab is designed to operate in a solar inertial attitude to provide maximum power from the solar cells and to support astronomical observations; to operate EREP in an earth viewing mode over a ground track it must leave this attitude, thereby expending consumables and decreasing the power supply. This restricts Skylab to one or two EREP passes per day. Except for system tests, data taken by EREP is not telemetered back to the surface, instead it is stored and returned with the crew. This weight and volume of tape and film also place an upper limit on data taking ability. In spite of these restriction Skylab will provide from EREP upon its completion: sixteen rolls of 5 mm film (450 frames per roll), 78 rolls of 70 mm film (400 frames per roll), nine rolls of 16 mm film for the viewfinder tracker (5,600 frames per roll), and 25 reels of 28-track magnetic tape (7,200 feet per reel).

Given the capabilities and restrictions of Skylab how can it best be applied to the problem of environmental monitoring? The system has the spatial and spectral resolution required to detect features of day-to-day concern, such as oil spills, but the restrictions of EREP would make such observations almost worthless for operational use. Such observations could, however, be used in research to determine the aerial extent of such spills under the existing conditions. The most promising application of Skylab to the problem of environment monitoring, however, does not appear to be the detection or tracking of specific contaminates, but rather that of providing a better understanding of the environment. These synoptic multispectral and sometimes repetitive views, used in conjunction with other data sources, and with models, are providing a new perspective to environmental observers. Examples of application are: Determination of the circulation patterns in an estuary, determination of areal extent of effect of air pollution on vegetation about a city, Determination of land use patterns and desirable land use patterns, modeling of atmospheric diffusion.

There are 148 approved Skylab EREP experiments in which the crew obtains the data requested over the site described and under the conditions desired (to the extent possible) by the investigators. In many cases, the investigator is acquiring complementary data at the surface at the time of the overflight. The investigators obtain no proprietary rights of the Skylab data. It goes immediately into public domain upon retrieval. The 148 investigations are broken down into nine broad discipline areas which are described here. Subdivision of these areas which are most likely to be of interest to environmental monitors are underlined, however, almost every investigation has as its prime or secondary objective a better definition of the environment or to test the feasibility of using high spatial and spectral resolution information acquired from spacecraft to better define the environment.

AGRICULTURE/RANGE/FORESTRY - 20 Tasks

Studies of crops, forests and rangelands, including management, resource evaluation, mapping and inventory information, crop identification, acreage estimation, irrigation needs, land productivity and crop vigor, soil surveys, soil conditions, soil distribution of insect infestations and freeze-thaw line/snow cover supportive studies.

GEOLOGY - 37 Tasks

Geomorphology, soil erosion, volcanic activity, resource and environment, geothermal anomalies, lithology, surface water loss, fault tectonics, earthquake hazards, geologic mapping, mineral exploration, highway engineering.

CONTINENTAL WATER RESOURCES - 17 Tasks

Mapping snow field distribution and water equivalent, investigating soil moisture distribution in plains area, measuring ice parameters, charting and cataloging estuary effluents, measuring changes in migratory bird habitats, delineation of good quality ground water and areas of high saline, and monitoring of flood control.

OCEAN INVESTIGATIONS - 16 Tasks

Obtain data on ocean currents, potential fish abundance, geoidal undulation, sea surface conditions, sea and lake ice, water depth, estuarine and coastal processes, water color and circulations and plankton population in upwelling areas.

ATMOSPHERIC INVESTIGATIONS - 13 Tasks

Various meteorological investigations, including mesoscale cloud, features, orographical effect on the formation of mesoscale disturbance, solar and terrestrial radiation measurements, aerosol concentrations, cloud statistics and characteristics, day/night detection of cirrus clouds and other particulates, severe storm environments, and stratospheric aerosol concentrations as a function of altitude.

COASTAL ZONES, SHOALS AND BAYS - 12 Tasks

Mapping hydrobiological communities, sensing bay and coastal environments, coastal water circulation, river plumes, sedimentology analysis, water depth analysis, water pollution, developing monitoring techniques.

REMOTE SENSING TECHNIQUES DEVELOPMENT - 11 Tasks

Relate signatures of EREP imagery to ground spectra, adaptation of discrimination techniques, radar altimeter terrain characteristics identification, microwave pulse response of rough surfaces, and sensors performance evaluations.

REGIONAL PLANNING AND DEVELOPMENT - 30 Tasks

Land use mapping, crop identification, acreage mensuration, urban studies, land classification, effects of strip mining, effluent water patterns, recreation site analysis, water resource development and management, transportation planning, assess fire damage and erosion sources.

CARTOGRAPHY - 8 Tasks

Photo mapping, map revision, map accuracy, thematic mapping, surveys, mapping techniques.

On the basis of samples of data taken from the first manned mission and telemetered data from the second mission, it appears that the EREP systems S-190A and B, and S-191 are performing as well as, or better than, expected. These preliminary data also indicate that S-192 is not quite performing as expected in all channels, however, considering the use of ground computer preprocessing techniques these data will be provided to a quality comparable to ERTS.

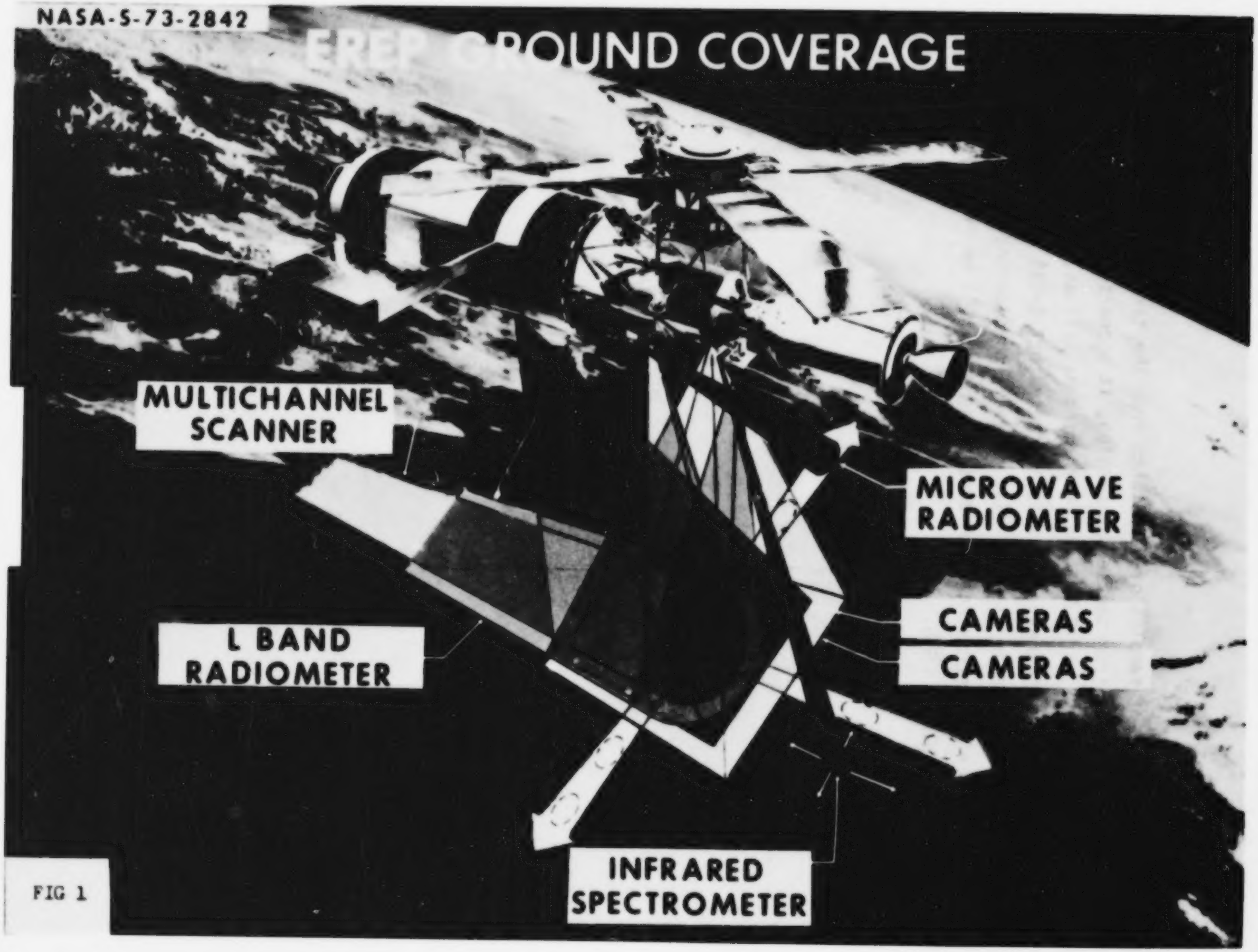
NASA-S-73-2842
EREP GROUND COVERAGE
MULTICHANNEL SCANNER
MICROWAVE RADIOMETER
L BAND RADIOMETER
CAMERAS
CAMERAS
INFRARED SPECTROMETER

FIG 1

ENVIRONMENTAL APPLICATIONS OF THE EARTH RESOURCES TECHNOLOGY SATELLITE

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On July 23, 1972 NASA launched the first earth-resources dedicated research satellite, called ERTS-1 (for Earth Resources Technology Satellite), into a near-circular, near-polar orbit at an altitude of 920 km (570 miles) (Figure 1). The satellite reoccupies the same orbital path every eighteen days, and thus it is possible, depending on cloud cover, to obtain up to 20 views of the same area in a year. The satellite orbits the earth about every 103 minutes. It carries a multispectral scanner (MSS) imaging system that produces images about 185 km (100 nautical miles or 115 statute miles) on a side. Thus an area of approximately 34,000 sq. km (13,000 sq. miles) is presented in a single image. Another imaging system, the return beam vidicon (RBV) is also on the satellite but a malfunction occurred in this system soon after launch, and the system was deactivated.

The MSS is a line-scanning device which records a scene simultaneously in four bands, each band image being composed of approximately 7.5×10^6 picture elements (pixels). The four solar-reflected spectral bands are: 0.5 - 0.6 um (green), 0.6 - 0.7 um (red), 0.7 - 0.8 um (near infrared), and 0.8 - 1.1 um (near infrared). Figure 2 shows the Salt Lake, Utah area imaged in the four bands. Note that the different bands bring out different features - for example, vegetation and water turbidity are best shown in the shorter wavelengths, while geologic structure and the water/land interface are best shown in the infrared images.

The video MSS scanner signal is converted to digital data and telemetered from the satellite to a receiving station on earth. The final data products which are produced at the GSFC Data Processing Center are digital tapes, black and white images of individual bands made from the digital data, or false-color composites of several bands. The resolution of the ERTS imagery is about 70 - 80 meters, approximately the size of a pixel, but varies depending upon the shape of the object and the contrast between the object and its surroundings.

There are approximately 330 NASA-supported investigations which use data from ERTS-1 in such disciplines as agriculture and forestry, mineral resources, water resources, land use, meteorology, and environment surveys. There are presently about twenty-seven investigations in the environment discipline, and about twice this number in other disciplines which are secondarily concerned with environmental problems. The following are just a few examples of environmental applications from ERTS gleaned from progress reports to NASA or papers presented at a symposium on ERTS results held in March of 1973.

To date, ERTS data have been found useful for a variety of environmental applications. Studies of air pollution, of fresh water and ocean water pollution, of disrupted land surfaces, of regional and local environmental management planning - all have used ERTS data successfully.

The New Jersey Department of Environmental Protection has found ERTS a unique tool for environmental planning [1] . Figure 3 is an ecozone map, prepared for the entire state from three ERTS images. Ecozones are defined as "regional areas characterized by homogenous interrelationships of soils, landforms, vegetation, geology, drainage and land use". Because of their regional areal size and uniform characteristics, the state considers that ecozones should logically be recognized as integral regional planning units. The ecozones listed below contain critical environmental resources, and the state Department of Environmental Protection has expressed a need for special protection and regulation of these zones: the coastal zone (coastal bays and wetlands); the pine barrens (unique forest associations and extensive aquifer zone); the agricultural belt (prime agricultural land); the highlands and the Kittatinny Mountains (relatively undistured forest areas). A small scale, synoptic view is required for the recognition and delineation of regionally similar land areas. The state of New Jersey found ERTS data uniquely suited to this purpose because each image covers approximately 34,000 sq. km (13,000 square miles).

Imagery from the ERTS satellite is also capable of contributing to environmental management on the local scale. The coastal wetlands environment is one which requires careful management because of its importance to wildlife and its value to land development. The Nanticoke River Marsh is part of the Chesapeake Bay wetlands network which provides food and habitat for a variety of marine life and which serves as one of the most important wintering areas on the Atlantic Flyway. ERTS imagery has been used for the development of a vegetation group classification map of the Nanticoke Marsh [2] .

The amount of flooding in a wetland area is a major determining factor in vegetation species mixture. "Low marsh" areas, or those which are most often flooded, cover the greatest area of the Nanticoke River Marsh. Large stands of Juncus roemarianus, Scirpus sp., Distichlis spicata, Spartina alterniflora and Salicornia sp. are found in these areas. Low marsh appears darker than high marsh on ERTS imagery because of the low reflectivity of the deep water in which the plants stand. The classification "high marsh" describes drier areas. These often occur at the wetland/water boundary where the land surface has been built up by deposits from streams. This category is largely made up of Spartina cynosuroides, Spartina patens/Distichlis spicata association, Iva futescens and Baccharis halimifolia.

The 10 October 1972 ERTS image was used to produce the vegetation map shown in Figure 4. High marsh and low marsh areas are mapped, together with a third classification described as low marsh/water. The latter has been established due to the difficulty in defining some of the interior boundaries. Low growth or sparse plant cover exhibit a very low reflectance because of the water background, and so are not easily distinguished from pools of surface water. The vegetation map also delineates major high ground islands which are covered with trees.

ERTS imagery is a useful tool for determining wetlands extent and boundaries, plant community composition, the position of mud flats and berms, the extent of ditching, filling and other man-related activities and successional trends in vegetation. Such information is required by federal agencies involved with wetland mapping and coastal zone management as well as by state agencies concerned with wetland and coastal problems. For use by these agencies, the specific, up-to-date information supplied by ERTS is uniquely applicable to studies of the constantly changing wetlands environment.

Several ERTS investigations of air pollution are presently in progress. Studies include those involving the location and monitoring of individual pollution sources, the altered reflected radiance from the surface as a result of air pollution, the effects of air pollution on vegetation, and the geometry and movement of air pollution plumes. One of these investigations has resulted in proof of the theory that pollution of the air in our cities can cause local weather modification [3] . Figure 5 shows an ERTS image of Lake Michigan taken on November 24, 1972. Particulate plumes are visible from at least seven steel mills and power plants located in the Chicago - Gary, Indiana area. The plumes feed directly into the shallow convective cumulus clouds over the lake. It is apparent that the smoke causes premature cloud formation, as those clouds along the plume line form noticeably closer to the shoreline and become more dense and well-developed over the lake. Snow was reported falling from these cloud "fingers".

Several investigations have demonstrated the usefulness of ERTS imagery for delineating strip-mined areas and for evaluating reclamation success. Because vegetation is highly reflective in the 0.8 to 1.1 um ERTS band and bare soil absorbs near-infrared radiation, the satellite images show distinct contrast among stripped land, partially vegetated areas and fully vegetated areas. In Figure 6 is shown an enlargement of an ERTS image of Indiana acquired in August of 1972. The two counties shown were last mapped for strip-mined acreage in 1968. The accompanying figure shows a map of stripped land made from this ERTS image [4] . The resulting map was in close agreement with inventory information obtained from individual coal companies. A comparison of the image and map reveals that certain areas which were mined before 1968 appear to remain partially or wholly unvegetated at the time of this ERTS pass. Acreage and reclamation status of stripped land can be monitored from the satellite on a yearly or even seasonal basis. Mapping these areas by ERTS imagery both saves time and reduces cost in comparison to the conventional ground survey methods.

Another application of ERTS in the area of disturbed land surfaces is the mapping of fire burns. The Division of Forestry in California is required to submit a fire map and fire report to the District Office within ten days after a wildfire has been extinguished. The present procedure for drawing up such maps requires that individuals walk or drive around the fire perimeter, drawing boundaries on a topographic map. For very large fires, low-flying aircraft are employed while an individual draws the fire boundaries freehand on a map sheet.

Figure 7A is a map of the Fiske Creek (left) and Pocket Gulch (right) fire burns, as it was drawn up by the California Division of Forestry. The CDF spent approximately 4 to 8 hours (including flying the fire to draw the map, plus time to use a dot grid for area estimation), or about $500, to map the Pocket Gulch burn. The map in Figure 7B was drawn in about 25 minutes (after the image was in hand) from an ERTS image of the burned area (Figure 7C) [5] . The cost of drawing up the ERTS map was about $50. Low altitude oblique aerial photography has indicated that the fire perimeter map in Figure 7B is more accurate than the one drawn up by the CDF.

A variety of studies involving water resources and water pollution have found ERTS to be a significant tool in the study of pollutional processes in lakes, in rivers and in coastal and estuarine waters. The satellite data have registered a variety of pollutant types including sediment, organic pollution such as sewage sludge, acid industrial wastes, oil slicks, and surface algal blooms. An example of the latter appears in Utah Lake in the Figure 2 images. The green algae, bearing reflective properties in the near-infrared spectrum similar to land vegetation, show white in the 0.8 to 1.1 μm ERTS band against the black of the highly absorptive water. The bloom is the result of an overabundance of nutrients such as phosphorous and/or nitrogen in the lake. Not only is the bloom an indication of the trophic state of the lake, but also demonstrates the pattern of wind circulation against the Wasatch Mountains east of Provo, Utah.

The October 11, 1972 image of the Washington, D.C. area (Figure 8) shows the Potomac River heavily laden with sediment which had washed down from the west in a heavy storm which occurred on the 10th of October.

Suspended sediment is more light-reflective than is clear water, and so it appears lighter in the image. The Potomac and the Rappahannock Rivers, whose watersheds drain from the west, are obviously high in sediment content in this image. However, the Patuxent River, which drains mostly from the north, and the Choptank and Nanticoke which drain the eastern shore of the Chesapeake Bay, are much less turbid, and therefore darker in color. It is apparent that on this day the sediment content in the Occoquan River (entering the Potomac from the west, south of the D.C. metropolitan area) was considerably lower than that in the Potomac. The outfall from this tributary, dark on the image, moves southward along the west bank of the Potomac, while the more turbid waters from the upper Potomac cling to the right. Gradual mixing occurs, and most of the heavily concentrated sediment has been dispersed before the entrance of the Aquia River and the Potomac Creek at the first major eastward bend.

While many of the investigations being carried out with ERTS-1 data have relied on photographic reproduction of the imagery, we find that digital interpretation and manipulation of the data products leads to a capability for resolving features which are indistinguishable in the photographic products and, in addition, allows identifications and/or correlations which are amenable to quantitative and statistical treatment. For example, the October 11 image, shown in Figure 8, has been studied in greater detail by computer analysis of the digital data [6] . Sedimentation in the Potomac and Anacostia Rivers on this date and on the preceding ERTS pass were compared using pattern recognition and multi-channel density slicing techniques. The result of the analysis is shown in Figure 9. Most of the sediment in the Potomac estuary in the 23 September scene was found either in the Anacostia River channel or downstream below Occoquan Creek. Low sediment values in the region below Roosevelt Island are associated with local sewage outfalls. Using this digital technique, most major sewage effluent sources in the estuary can be located. The very high sedimentation values found in the Anacostia are from two major sources: a sand and gravel operation, and runoff from open surfaces associated with construction of roads and buildings. When compared with the earlier image, it is clear that the heavy storm runoff on October 11 has resulted in high sedimentation levels throughout the estuary, obscuring effluent outfalls.

Several types of water pollution were identified in an ERTS image of the New York Bight area. Figure 10, which is an enlargement of the red ERTS band image of that scene provides an excellent example of the detectability of industrial wastes, sewage sludge, pollution plumes and water mass boundaries in estuarine waters by ERTS imagery [7] . The serpentine curve in the ocean south of the center of the image represents a dumping of acid-iron wastes, containing about 8.5% H_2SO_4, 10% $FeSO_4$, and small quantities of various metallic elements. Immediately to the north of this spill is a dark outline indicating a sewage sludge dump, and directly to the west of the dump can be seen the polluted waters of New York Harbor. Note the almost physical boundary between the harbor waters and the ocean. Ground truth confirmation of these features was obtained by aircraft underflight and the waste disposal authorities of New York City for the day of the pass, August 16, 1972. Continued monitoring of such features provides useful information about circulation patterns, thus aiding in the optimization of ocean dumping for maximum dispersal and minimum environmental impact.

In summary, although monitoring of pollution and environmental degradation by satellite remote sensing is inherently less specific than in-situ measurements, it has the advantage of global and repetitive coverage, thus providing the basis for an economic, operational capability. Unfortunately, the temporal or spatial resolution of the ERTS system is not satisfactory for many environmental problems. Ideally, a satellite system dedicated to environmental monitoring should have a spatial resolution of at least 10 meters, be independent of cloud-cover or sunlight restrictions, and should be able to essentially continuously monitor any particular area. The study of images received from the first Earth Resources Technology Satellite, however, has demonstrated the capability of remote sensing by satellite to detect and monitor naturally occurring environmental changes as well as man-induced stresses to the environment.

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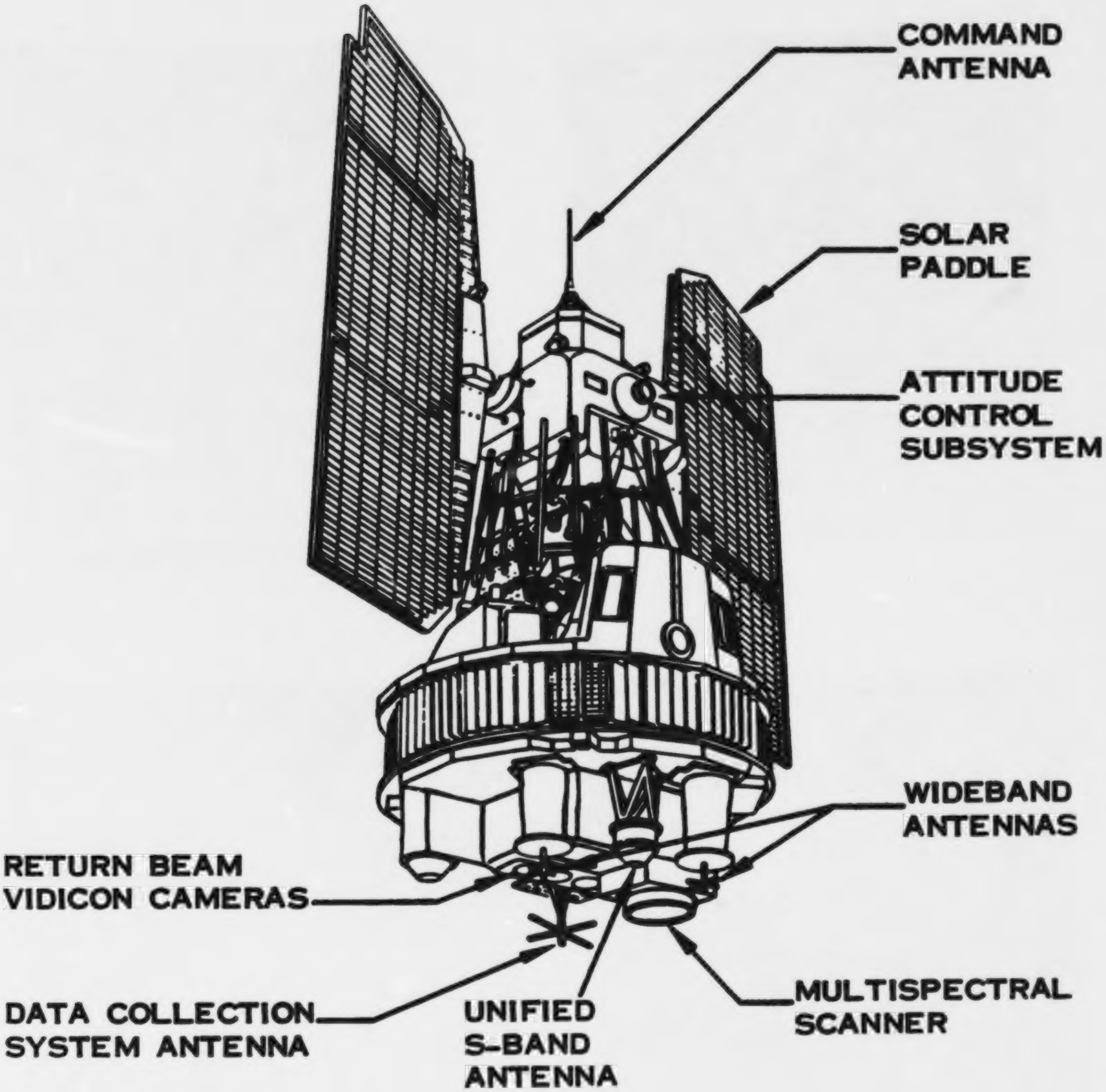


Figure 1. The Earth Resources Technology Satellite.

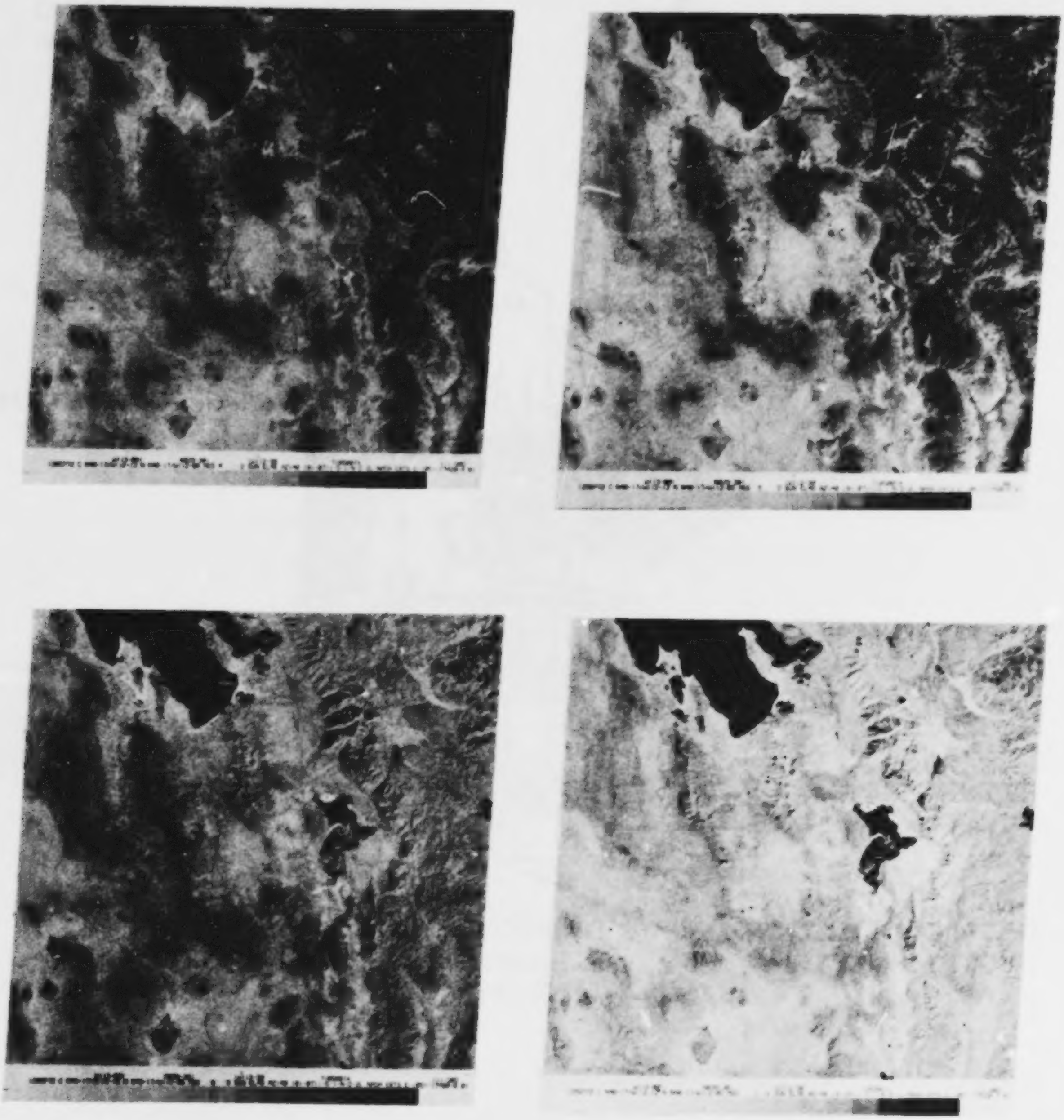
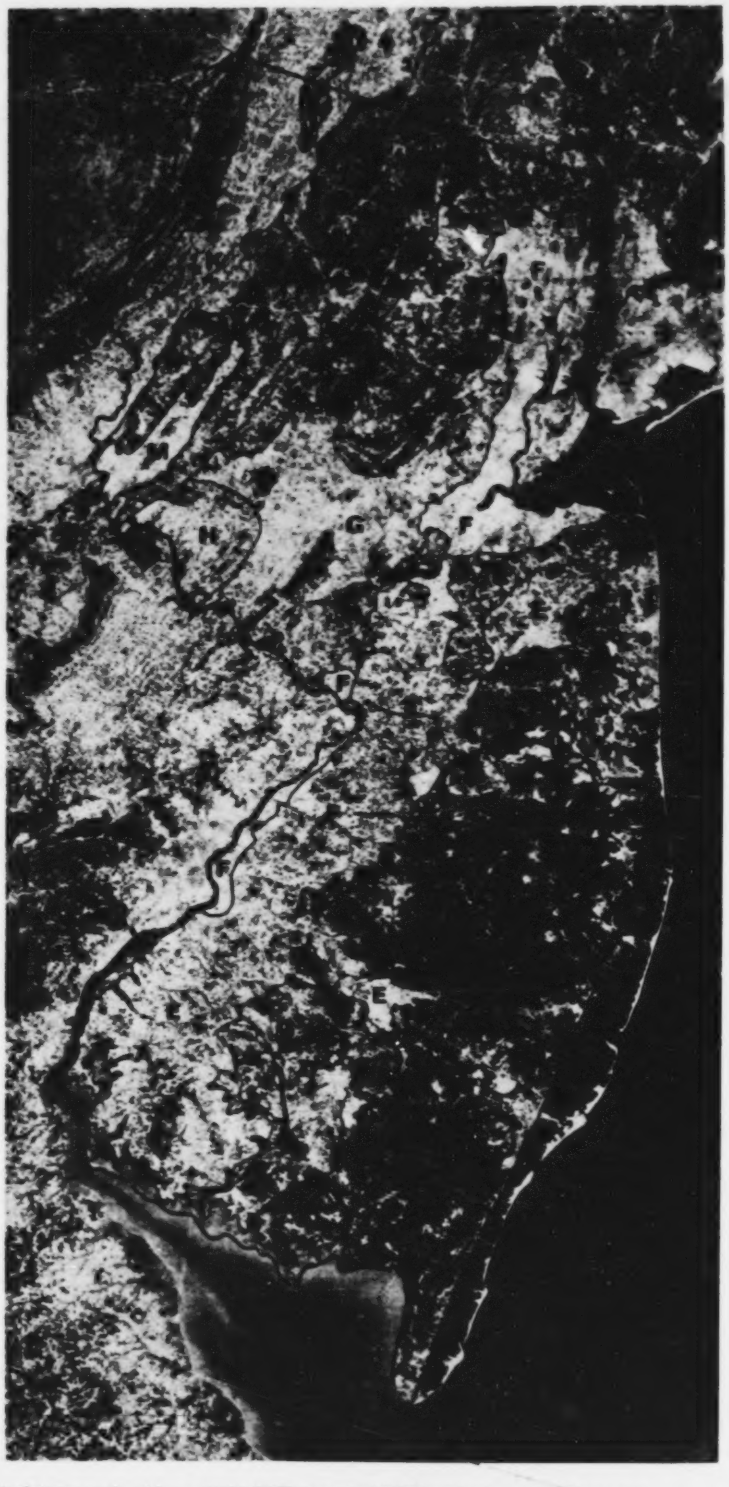


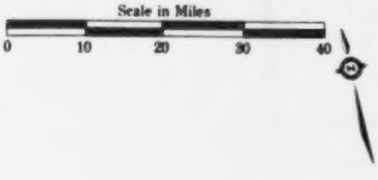
Figure 2. ERTS imagery of the Salt Lake City, Utah area: 0.5-0.6 µm band upper left, 0.6-0.7 µm band upper right, 0.7-0.8 µm band lower left, 0.8-1.1 µm band lower right.

REGIONAL ECOLOGICAL MAP
NEW JERSEY



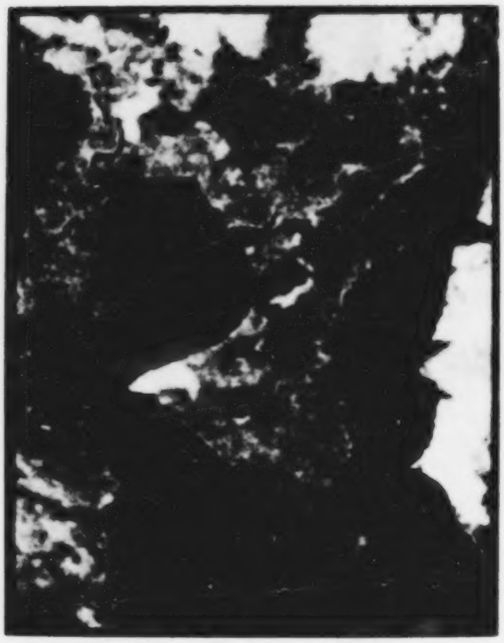
LEGEND

A COASTAL ZONE: coastal lands, wetlands and water directly affected by coastal processes
B PINE BARRENS: contiguous forest cover with low intensity land use
C LAKEWOOD: forested area with mixed residential and commerical land use
D VINELAND: mixed agriculture and forest
E AGRICULTURAL BELT: extensive farmland with small woodlots and some urban development
F URBAN AND INDUSTRIAL ZONE: areas of intensive land use
G PIEDMONT PLAIN: mixed cropland and urban land with scattered forested traprock ridges
H HUNTERDON PLATEAU: curvilinear forested ridges and cleared valleys
I UPPER DELAWARE RIDGE AND TERRACE: rolling terrain with forest and agricultural use
J KITTATINNY MOUNTAIN: steep series of forested ridges with low intensity land use
K KITTATINNY VALLEY: rolling topography with forested ridges, cleared valleys (agricultural use), and numerous small lakes
L HIGHLANDS: rugged, partially forested area with numerous lakes
M WASHINGTON: level valley (rural land use) enclosed by Highlands Ecozone
N PASSAIC BASIN/WACHUNG MOUNTAINS: forest cover and urban land use in a level river basin ringed by forested, traprock ridges
O RIDGEWOOD: urban land use and forest cover

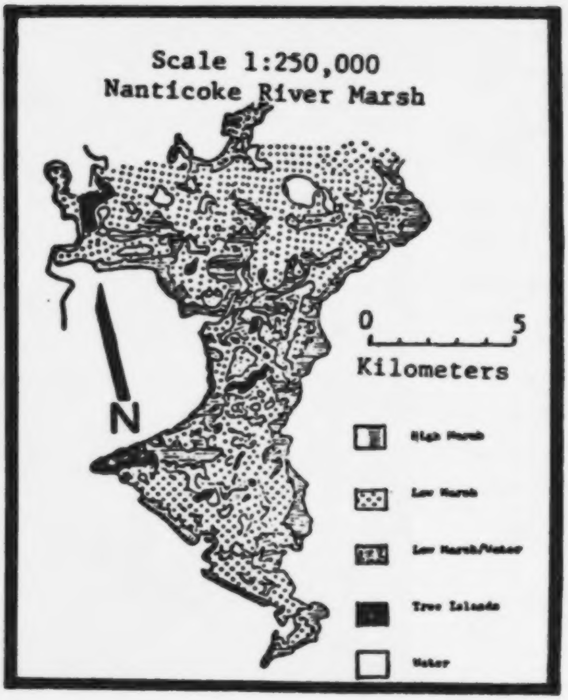


This photomap produced from a NASA ERTS-1 mosaic of MSS band 5 taken on October 10, 1972

Figure 3. New Jersey ecozone map made from ERTS imagery.



1:250,000 enlargement of Nanticoke R. salt marsh.



1:250,000 map of Nanticoke River marsh.

Figure 4.

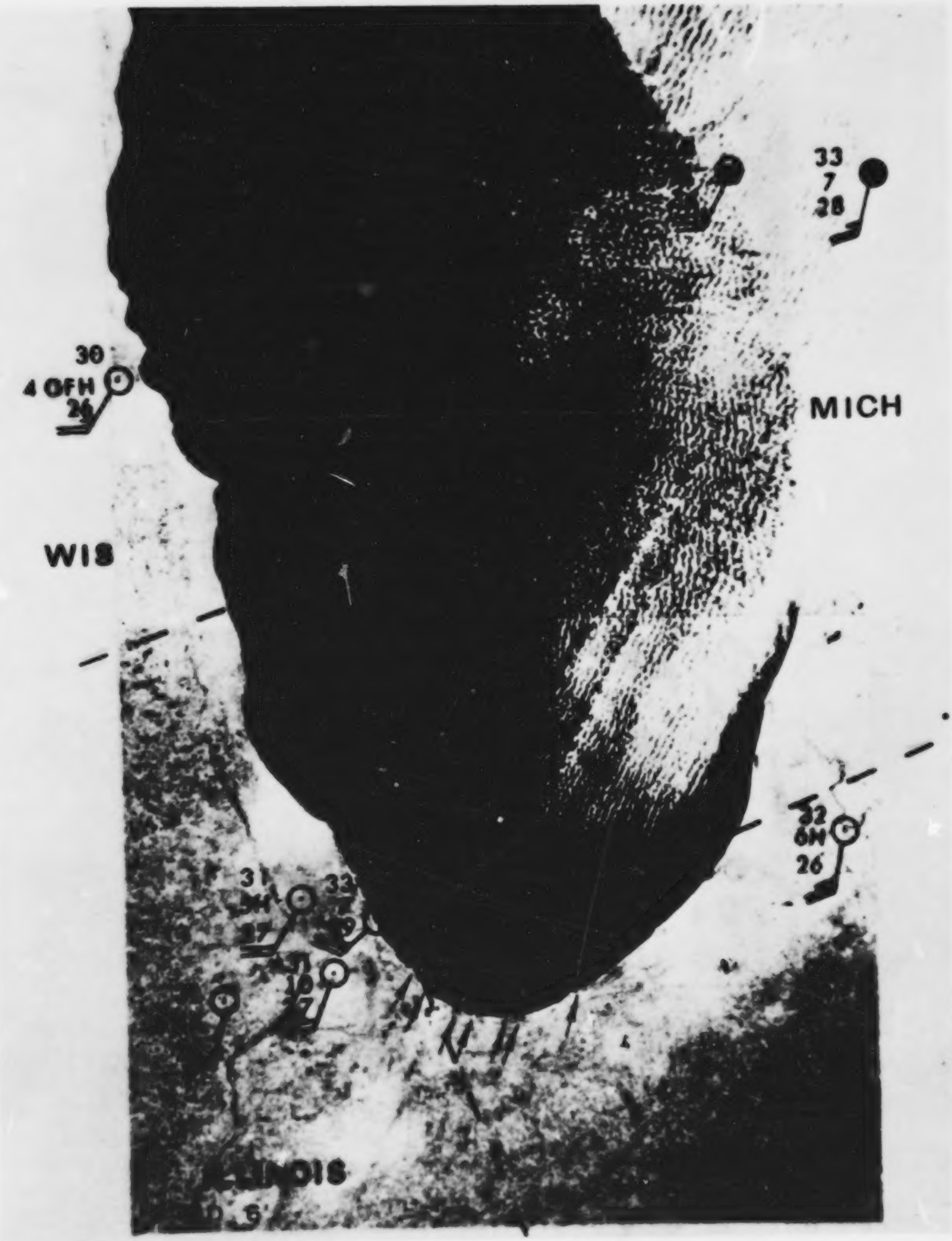


Figure 5. ERTS mosaic of Lake Michigan showing inadvertent weather modification by pollution plumes.

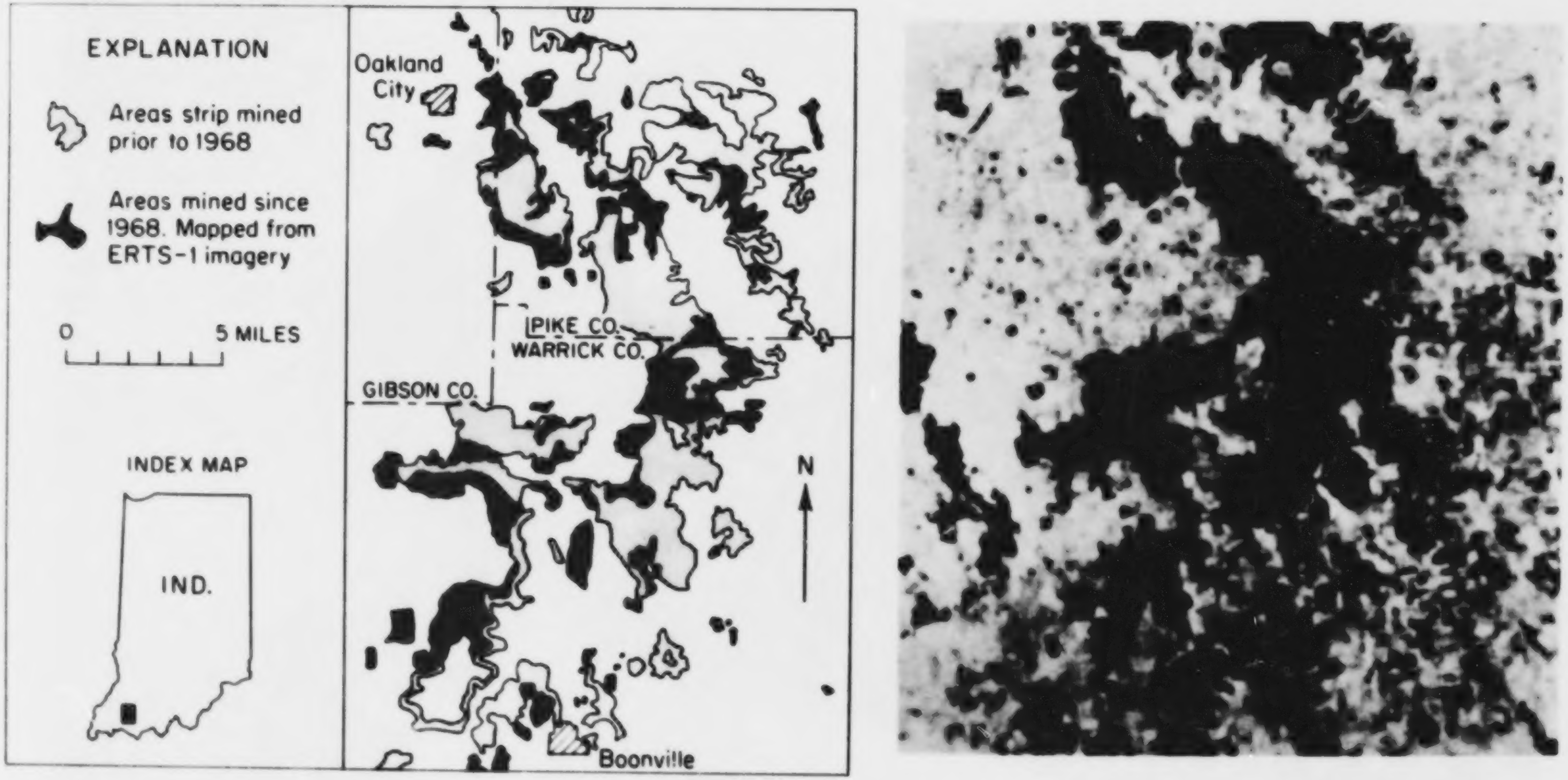
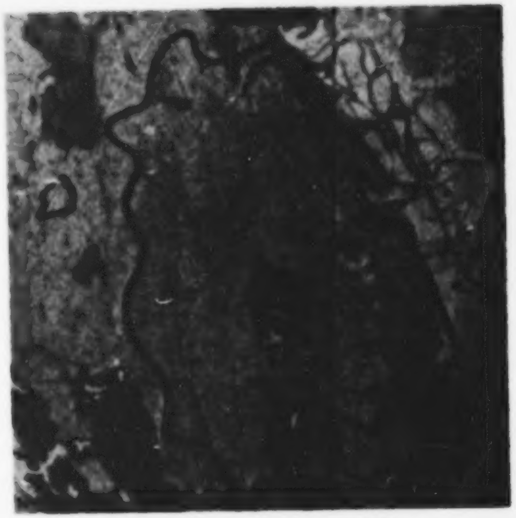
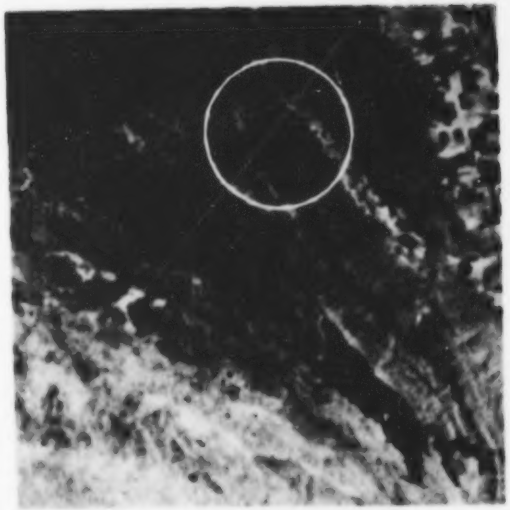


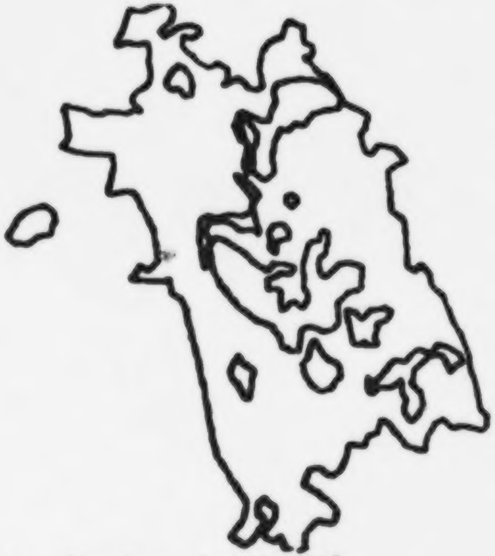
Figure 6. Indiana strip mine map and enlarged ERTS image.



A. (Scale = 1:125,000)



C. (Scale = 1:780,000)



B. (Scale = 1:110,000)

Figure 7. (A.) Ground survey map, (B.) ERTS data map and (C.) ERTS image of fire scars in California.

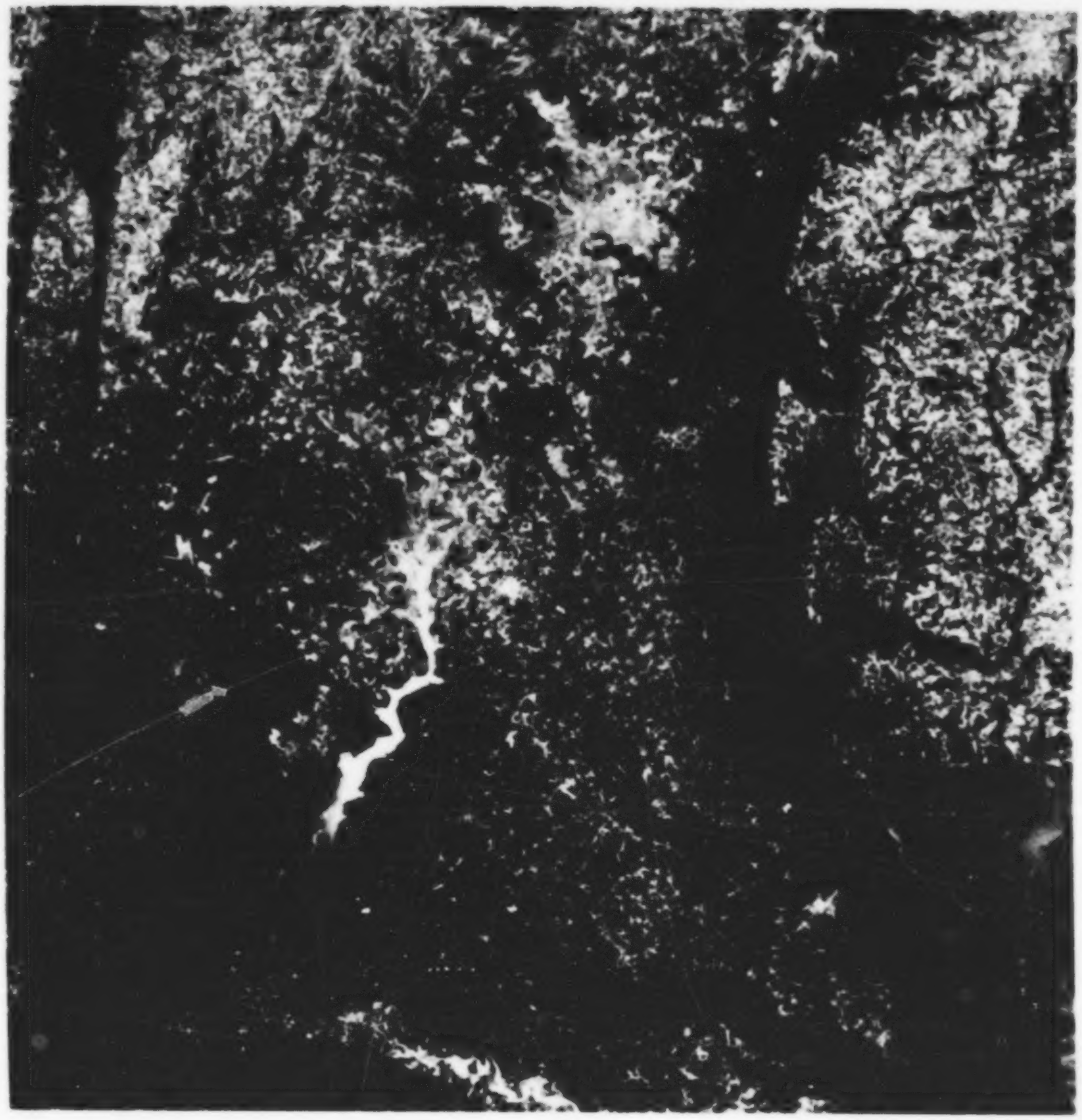
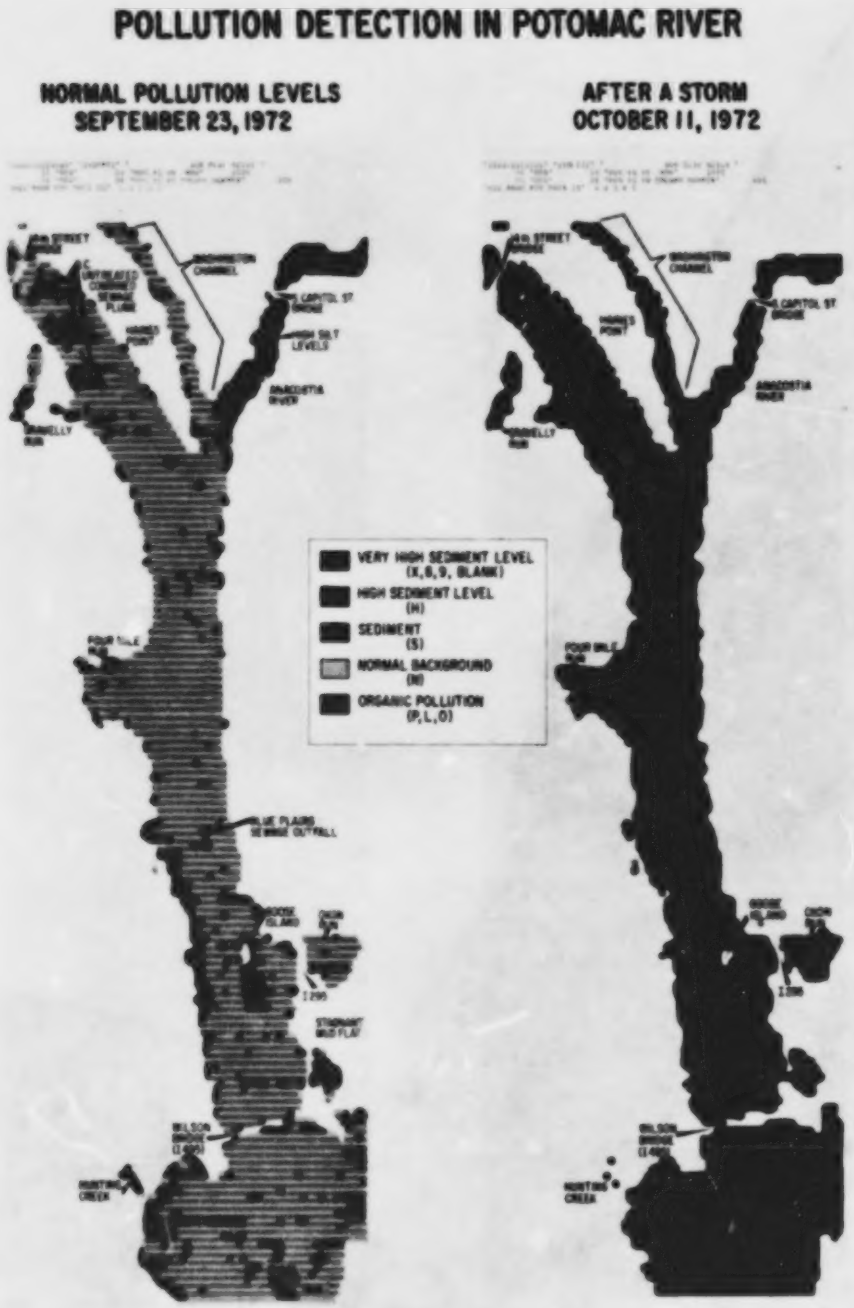


Figure 8. ERTS red band image of the Washington, D. C. area.



POLLUTION DETECTION IN POTOMAC RIVER

NORMAL POLLUTION LEVELS
SEPTEMBER 23, 1972

AFTER A STORM
OCTOBER 11, 1972

ERTS DIGITIZED DATA
AMERICAN UNIVERSITY ERTS PROJECT UN443

Figure 9. Digital enhancement of ERTS data for two dates at the confluence of the Potomac and Anacostia Rivers.

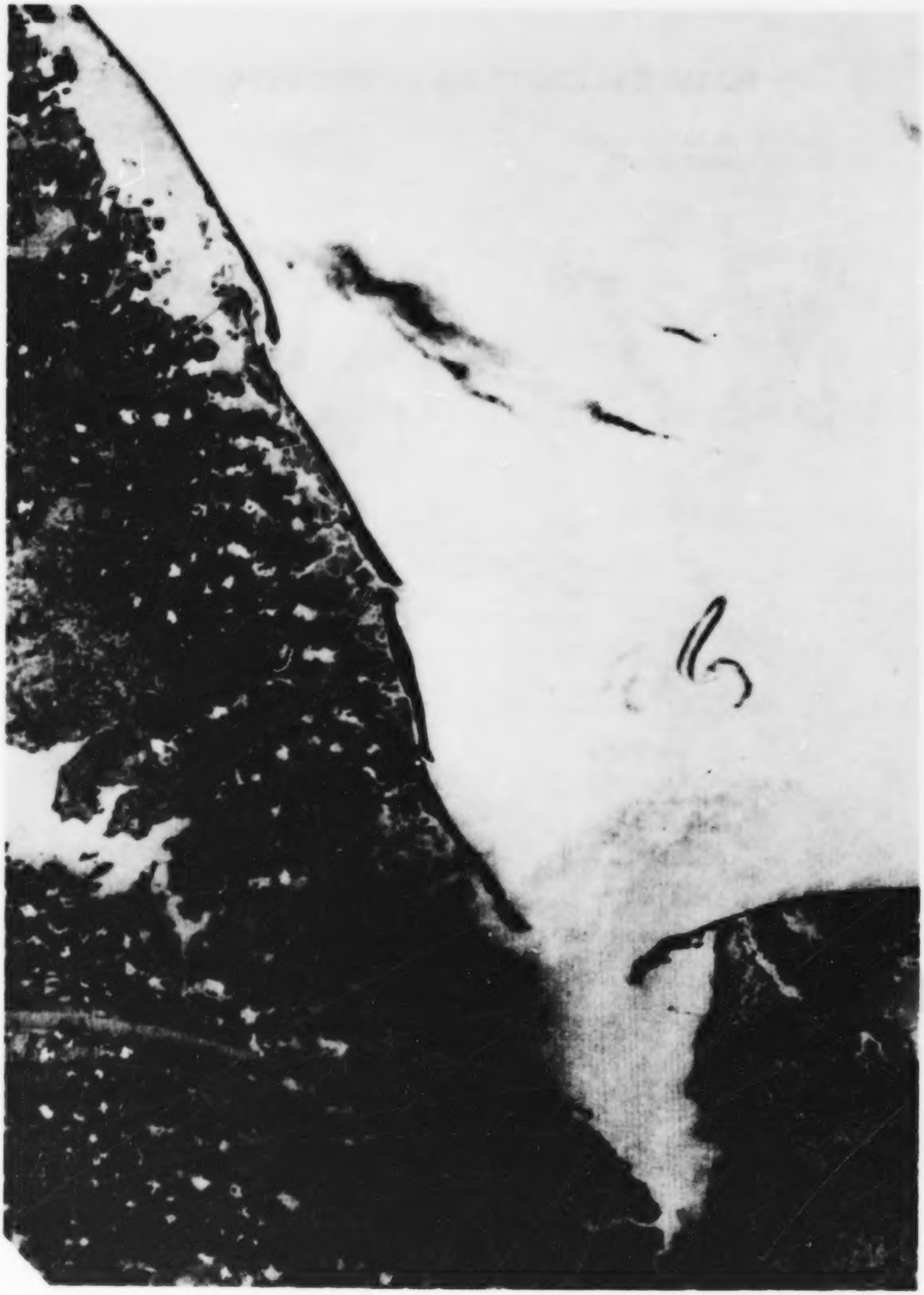


Figure 10. Industrial waste and sewage sludge dumps in the New York Bight area.

ERTS-1 DETECTION OF ACID MINE DRAINAGE SOURCES

by

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638-6469

ERTS-1 DETECTION OF ACID MINE DRAINAGE SOURCES

Sponsored by EPA's Office of Water Programs and Office of Monitoring, through their interagency agreement with NASA LaRC we are using data from ERTS-1 in a program to locate and monitor sources of acid drainage pollution from the coal fields in the Upper Potomac River Basin.

ERTS-1 was launched by NASA in July, 1972. Three of its unique features have been brought together for the first time in resource inventory and monitoring. These are spatial coverage of 34,000 square kilometers on each image scene; repetitive coverage of any area on earth every 18 days; and registered simultaneous viewing in four separate, spectral bandwidths ranging from green to near infrared.

This new technology has potential application to locating sources and identifying causes of pollution on earth. As you have seen, ERTS images show contrasts in areas of known pollution. These data require further interpretation and confirming measurements to determine the nature and quantity of the polluting source. The development of a data acquisition program appears feasible which will utilize these data and could be used to monitor large land areas for pollution resulting from surface and shaft mining operations as well as other causes. Continuous monitoring of these areas may well indicate the status of both existing and new pollution sources. Such rapid detection capability will allow corrective action to be promptly implemented.

Description of ERTS-1 data appear elsewhere. Suffice it to say that analysis of the imagery shows that the performance of the Multi-spectral Scanner (MSS) is excellent. There is clear separation between the bands and ground resolution is approximately 150 feet. Of interest to EPA, indications of stream flow, algae blooms and sedimentation and dispersion patterns have been noted. Urban areas show clear differences from current land use maps (in many cases based on data 5-10 or even 40 years old) and watershed topographic features (including surface-mined terrain) stand out in clear detail.

With these facts in mind EPA and NASA have contracted with Ambionics to perform a study and test of the applicability of using ERTS data, combined with aircraft data and traditional methods to inventory the sources of mine drainage pollution in the Upper Potomac Basin.

It is our intent in this program to investigate the best means of integrating this new source of data into a total EPA monitoring system. By demonstrating the usefulness of advanced technology and remote sensing to EPA's needs in one small area we hope to provide a model for larger scale future applications.

The Potomac River is entirely within the state of Maryland, but is fed by tributaries from Pennsylvania and West Virginia as well as Maryland. The Maryland Water Resources Administration Laboratory at Cumberland, Maryland and its corresponding member in West Virginia have extended their cooperation to not only take periodic field samples but to provide their analyses. These include the following:

pH
Total Solids
$CaCO_3$
Ferrous Iron

Ferric Iron
Aluminum
Sulfates
Turbidity

We are now identifying and acquiring existing data about the region. These include existing maps, photographs, and reports compiled by agencies such as USDA, SCS, BuMines, State Game and Fisheries Commission, etc. These data are in the form of aerials, reports, land use maps, etc. We have had excellent cooperation from the local authorities and have a flood of data coming in. In addition, we are monitoring and acquiring normal and special data collected during the period of the study. (i.e. surface data taken contemporaneous with NASA or state aircraft sensing, and/or ERTS passage over the test site.) This will extend throughout the length of the contract.

We have identified and ordered from USGS EROS the applicable ERTS images. Now that the EROS computer is back on line, we should have this data shortly.

Analysis will proceed in this approximate sequence.

Location of pollution sources and types on the ERTS imagery from the previously obtained data. As a control, tributaries within the test site known not to be subject to mine pollution, such as Patterson Creek in West Virginia, will be studied to determine the appearance of regional tributaries not subject to degradation from active or abandoned mines.

Topographic changes resulting from surface mining activities shall be located on aircraft data and marked on ERTS frames.

With the locations determined and checked through utilization of maps and identifiable landmarks the following will be checked for appearance and compared with the previously obtained surface data:

Texture (degree of coarseness)
Shapes
Associations of shapes
Response to varied color bandwidths

All of the above will be analyzed by seasons, location, and relationships to developments (including mines) and general direction of slope. From these factors patterns will be sought relating vegetative cover types to topography and drainage basins.

While other investigators report the identification of acid pollution in water, our primary approach will be to use

ERTS in conjunction with traditional methods to identify land use and pollution sources as well as secondary effects of pollution e.g. ecological degradation along stream banks.

Our next step will be analysis of the ERTS transparencies using I^2S Additive Color Equipment for enhancement of image features and varying color bandwidths in combinations and different degrees of intensity. Results will be recorded for each image.

A land use map will be prepared based on current U.S.D.A. thematic maps presently within each county. However it may be necessary to redefine or modify existing classifications to types more similar to systems presently in use in the Census Cities program. This latter is readily digitized and will save time and money when used with the new G.E. Image 100 computer system using ERTS images, coded information and CCT's.

Utilizing the data from surface investigations and aircraft to establish accurate controls, the G.E. Image 100 system will be tested and adjusted for accuracy in its interpretation of the ERTS data entered into the system. Once perfected, this program may be employed on consecutive mine drainage search and control programs.

The land use maps based on ERTS will be studied for the appearance of areas known to be subjected to mine pollution and similarities noted. Areas of similar appearance, but heretofore unchecked or with little previous record of despoliation will be subject to surface and aircraft investigation.

This analysis technique should improve upon the efficiency of small staffs, traveling over large areas of difficult terrain taking small samples in the field often at long intervals, and too often sampling downstream samples of pollution from unknown sources, whether surface or subsurface, or broken seals.

We have had great cooperation from the West Virginia Department of Natural Resources and the Maryland Department of Water Resources in not only obtaining stream samples and analyses on specific sites but also maps on farmed areas, forests and cutover lands, county roads, trails, paths, and wet weather springs.

The area office of the U.S.D.A. Soil Conservation Service has an aerial photointerpretation section which has recently completed land use survey maps based on aircraft photography. At this writing we have supplied and ordered larger scale ERTS-1 imagery and the SCS is transcribing its data to the ERTS imagery.

Mine locations within the Test Site and their relationships to the steep choppy topography characteristic to this area is, in our opinion, a key element to this program. Direction of slope, rate of fall per mile of principal streams and their tributaries, and stream density [Total length of stream in a basin (miles) divided by area of basin (sq. miles) = stream density (sq. miles)] will contribute to the distribution, strength, and rapidity of spread of acid mine pollution. The Federal Bureau of Mines Eastern Field Operation Center mapping office is locating all abandoned and existing known mine sites on topographic maps. These data are computerized by topographic sheet title and are readily available. All such data for the Upper Potomac Basin test site are now being transposed onto tographic sheets obtained by Ambionics from U.S.D.I. and from there will be plotted on ERTS-1 imagery.

Similarities will be sought on the ERTS imagery common to the affected areas. The I ^{2}S Additive Color process and the G.E. Image 100 will be employed particularly where topography affects vegetative patterns and possibly emissions and reflectance. It is here that the land use maps may be most useful. Other features noted will be changes and differences in colors, shadings, textures, shapes and combinations of the above which can be indicative of degraded areas in the test site. A close watch will be kept for seasonal and annual characteristics which may provide dynamic indicators of acid mine pollution that can be applied elsewhere.

Our ultimate goal is to formulate a methodical approach in locating and monitoring mine polluted waters that will be more efficient and economical than techniques in existence today. These is promise of greater success in dealing with this earthbound problem through space technology than has previously been possible.

WATER QUALITY ANALYSIS USING ERTS-A DATA

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Abstract

The magnetic digital tapes of the imagery obtained by ERTS-A on September 23, 1972, have been analyzed for selected areas of the Chesapeake Bay and the Potomac River. A statistical analysis of all four bands has been carried out. The results show that band III is useful in determining the water to land interface. Data on bands I and II suggest the existence of three distinct types of water those having low, medium and high reflectivity. Available information from published literature shows that suspended matter (silt) produces higher than normal reflectivity. It is reasonable therefore to suggest that the recorded area of high reflectivity contain high concentrations of suspended matter.

A computer processing technique has been developed which identifies the above areas and produces thematic maps showing their geographical distribution.

1. INTRODUCTION

Remote sensing is now rapidly becoming an important tool in the detection and surveillance of water pollution. The basic physical concepts which led to the present developments were developed by a number of investigators some of which are F. Hulburt(1), J. Williams(2), and S. Duntley(3). Application of remote sensing techniques to oil slick detection have been made by N. Guinard(4), J. Aukland(5), J. Munday(6). Water quality measurements have been carried out by M. Querry(7) and J. Scherz(8), M. Golberg(9) has experimented with Raman scattering techniques. P. White(10) has carried out a study of the spectral characteristics of sewage outfalls.

A great opportunity for the further development of the art of remote sensing appeared in NASA's Earth Resources satellite program. A large number of data for extended geographical areas become available and it appears that some significant results have been obtained. Some relevant work has been carried out by the following investigators: V. Klemas(11), B. Bowker(12)and Rugles(13) have studied the dispersion of high sedimentation plumes from photographic images. C. Wezernak(14), H. Yarger(15), R. Mairs(16) and J. Schubert(17) also have investigated the surveillance of areas with high sedimentation.

The present paper is an additional contribution to the effort of assessing water quality from digitized ERTS-A imagery.

2. THE REFLECTANCE OF WATER

The satellites observations were made by using the Multispectral Scanner (MSS) which has four spectral bands. The bands are defined in Table I.

TABLE I

MSS SPECTRAL BANDS

Band	Spectral Width in Micrometers μ	Resolution bits	Gray level
I	.5 - .6	7	127
II	.6 - .7	7	127
III	.7 - .8	7	127
IV	.8 - 1.1	6	64

The information is transmitted digitally and then it is converted to a photographic product. Each digital count represents the radiance of a cell of 50 by 80 meters. It is important to notice that while the information is recorded at the tapes with a 7 bit resolution (127 gray levels) the photographic products are seriously degraded. Only a fraction of the gray level resolution remains at the photographic products (16 gray levels). It is very important therefore to recognize that accurate radiometric work can only be carried out with computer compatible tapes (CCT).

The total reading which is recorded at the satellite is the product of a number of complex physical phenomena several of which will be discussed below.

The radiance L is given by the well known expression

$$L = \frac{R}{\pi} HT + L_A$$

where R is the reflectivity of the target

H Irradiance illuminating target

T Transmissivity of Atmosphere

L_A Path Luminance

It is important in the course of our investigation to establish the order of magnitude of these quantities.

H. Rogers(17) by measuring separately the ground reflectance has published some typical values for Barton Pond, which is a small lake. They are:

TABLE II

RADIANCE READINGS FOR BARTON POND
Sun, Zenith angle 49°, Date: 9-28-72 (From H. Rogers)

BAND	L mw/cm^2/sr	bits	L_A mw/cm^2/sr	bits	T	R %	H mw/cm^2
1	0.476	24.3	0.274	14	.810	9.3	8.41
2	0.242	15.3	0.118	7.5	.865	5.5	8.14
3	0.141	10.3	0.082	6	.909	2.8	7.38
4	0.234	3.50	0.1062	1.5	.913	0.9	5.02

Note in the above table that the path luminance is approximately 50% of the total reading. This is potentially a source of large errors because of the uncertainty in its determination. Also it is significant to observe that the reflectance of the water in band III and IV is small. This takes place because the incident light is mostly absorbed. A number of other investigators have also studied the optical properties of the water and it has been established that an optical window exists which is approximately .2μ wide in the visible range. The peak of the window lies somewhere between .4 and .5μ depending on the physical composition of the water. For example for distilled water J. Williams(2) shows that the peak is at 3μ and the penetration length is approximately 100 m. The same data show approximately that average penetration length for band I and II of MSS is approximately 10 and 1 meter respectively. For natural water the peak of the window is shifted towards higher wavelength and the penetration length naturally decreases.

A large number of experiments have been made to determine the spectral response of the water as a function of its constituents. The results are difficult to relate quantitatively with ERTS-1 data because of the variable atmospheric conditions. In general however the following qualitative conclusions can be drawn. Algae is expected to give low readings in band I, medium in II and high in III and IV. Sedimentation is expected to give high readings in all bands except IV.

In this study no independent readings were taken at the ground consequently it was impossible to make absolute radiometric measurements. It was possible however from the relative radiance of the scene to derive a substantial amount of information. It was found that the best procedure was to use band III to identify water and then band II to assess the water quality. This is discussed in greater detail in section IV.

3. WATER QUALITY CONDITIONS IN THE UPPER POTOMAC RIVER TIDAL SYSTEM

The Potomac River is one of the most environmentally stressed areas in the Middle Atlantic states.(19) Effluents from a number of major wastewater treatment plants serving a population of about 2,500,000 people are discharged into the system. Figures I and II show the geography of the region and the major wastewater sources. Some of the important physical phenomena which characterize the Potomac are discussed below.

a. Tides

The tidal system extends from the Chesapeake Bay all the way to Little Falls in Washington, D. C. The time at which the satellite was taken was 9:20.2 A.M. E.S.T. which is 1 hour and 40 minutes after the high tide. This means that approximately one third of the tidal movement has taken place and that plumes should point downstream.

There are two areas which have presented tidally induced problems. These are the Anocostia River and the Piscataway Creek. In the Anocostia River the exchange rate is very small and consequently the high loads of silt which are discharged into it remain entraped for long periods of time.

A similar phenomenon takes place in the Piscataway Bay. In this region it has been observed that the wastewaters of the Piscataway Sewage Treatment Plant (10 MGD) have a very small dispersion rate and occasionally reach Broad Creek which lies upstream.

b. Water quality measurements

Unfortunately at the time of the satellite overpass no ground data were taken. There are however data taken at an earlier date, 9-6-72, close to Low Tide Slack (13.32) which provide some insight into the state of water quality of the Potomac.

The data is shown in Table III and the location of the stations is shown in Figures I and II. From the results the following observations can be drawn.

1. In the Key Bridge region a high chlorophyl reading (54.8 μg/l) and low Secchi Disk reading (26.0") probably indicate a high concentration of algae.

2. In the 14th St. Bridge region a low chlorophyl reading (21.0 μg/l) and a high Secchi Disk reading indicate a patch of clear water with low concentration of algae and sediments.

3. The most environmentally stressed area is the W. Wilson Bridge station where the dissolved oxygen (2.27 mg/l) has its lowest value, the nutrient loading its highest (1.35 PO_4, 1.90 NH_3 in mg/l) and the chlorophyl count is medium (28.5 μg/l). This takes place because this region is downstream of the two most important sewage treatment plants in Arlington (20 MGD) and Blue Plains (300 MGD).

4. In the Mathias Point region an interesting phenomenon is observed. Going from stations 15 to 15A and 16 the salinity nearly goes up by a factor of four, the chlorophyl count decreases by factor of two and Secchi Disk Depth increase by a factor of two. These data indicate that at some point in between lies the salt to fresh water interface.

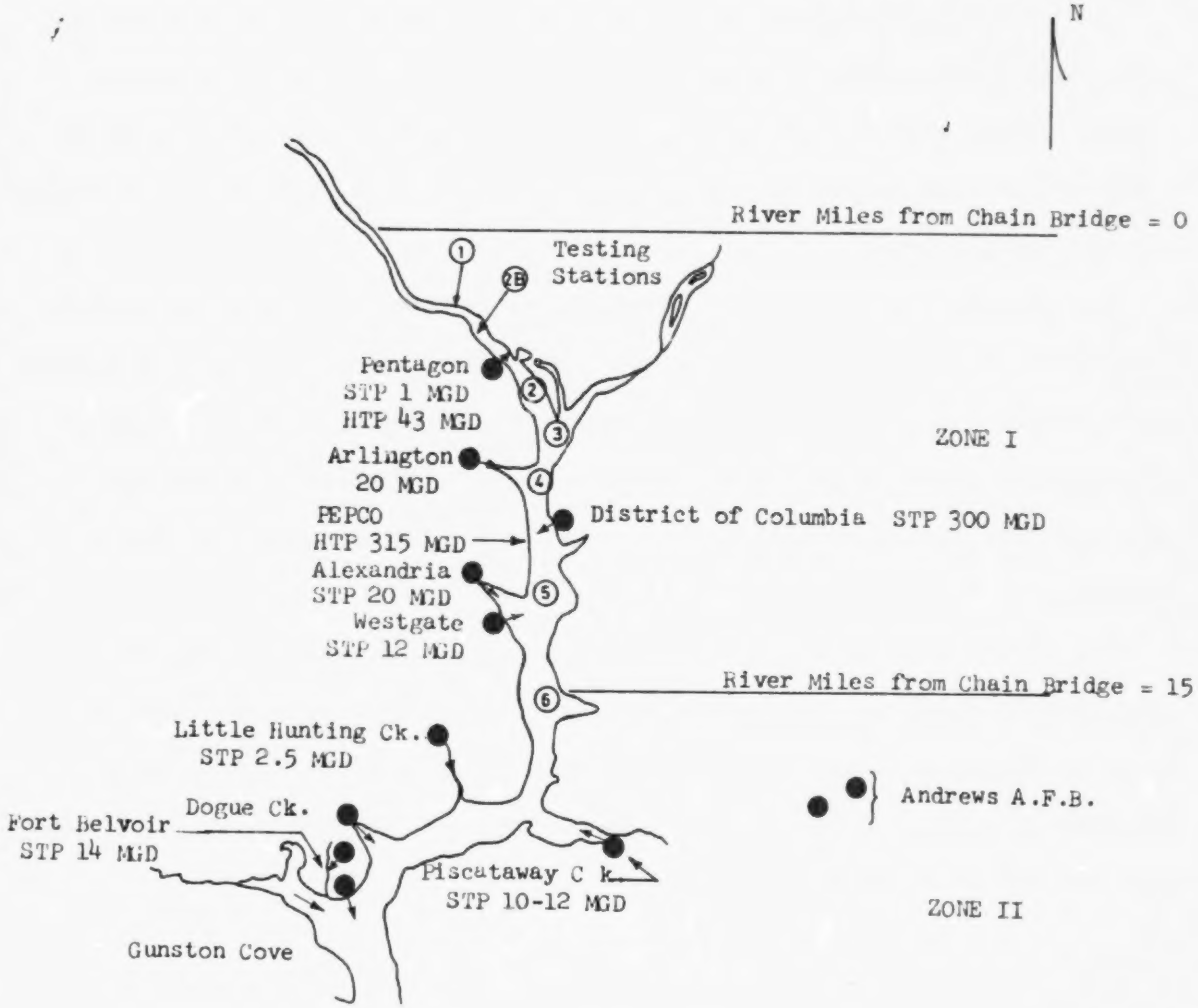


Figure I

Wastewater Discharge Zones
in Upper Potomac Estuary

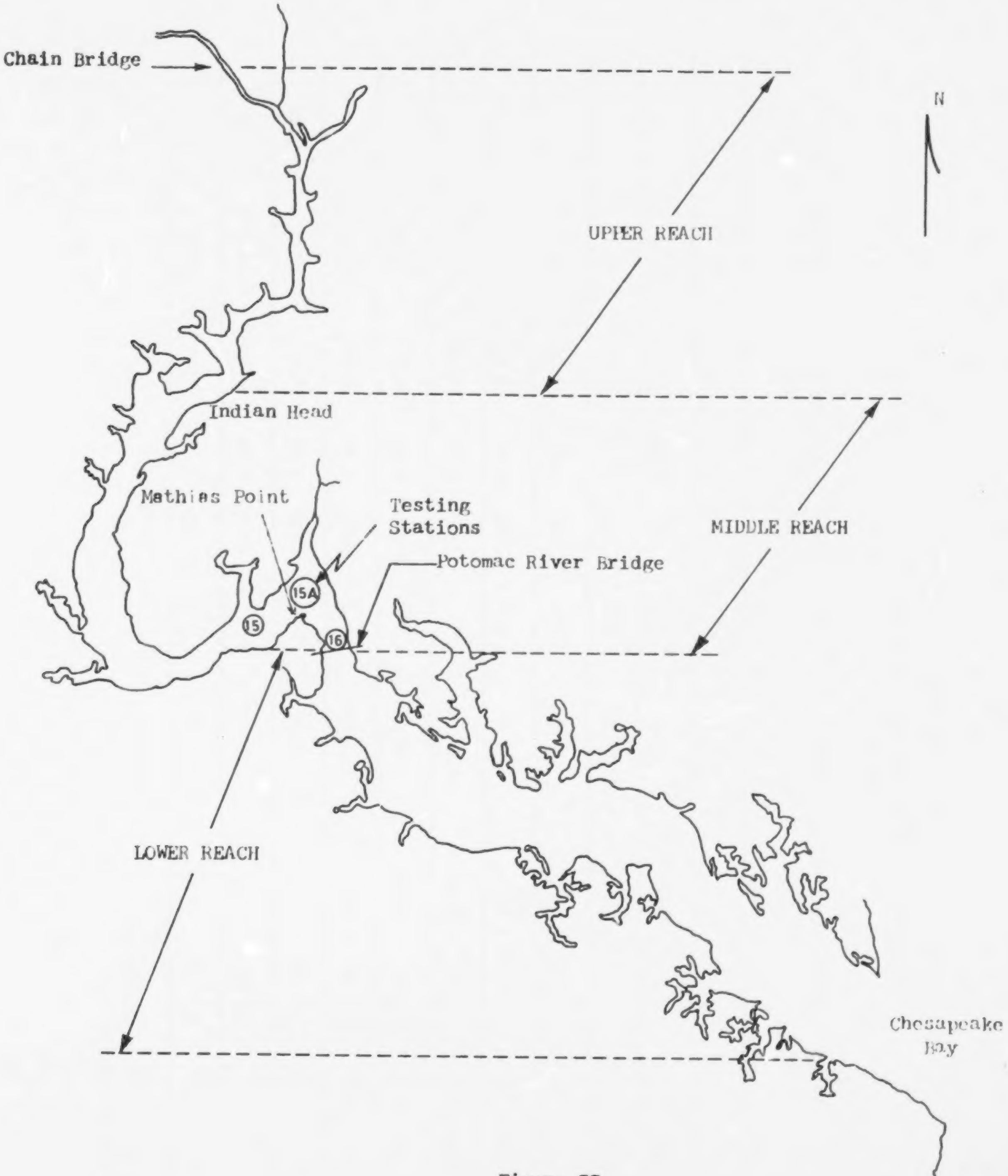


Figure II
Potomac River Tidal System

TABLE III

WATER QUALITY MEASUREMENTS

DATE: 9-6-72

Stations	River Miles	Time	Secchi Disk Inches	Water Temperature ^{o}C	Total P PO_4 mg/1	NH_3-N mg/1	DO mg/1	Total C mg/1	Chlorophyl µg/1	Salinity ppt 0/ 00
1. Key Bridge	98.3	11.20	26.0	23.0	.233	.130	8.61	29.72	54.8	
2. Memorial Bridge	97	11.35	30.0	23.5	.243	.070	8.02	30.71	43.5	
2A. 14th St. Bridge	96	11.45	34.0	24.0	.244	.100	7.39	30.95	21.0	
3. Hains Point	94.5	11.55	24.0	24.5	.399	.260	5.27	27.85	22.5	
4. Bellvue "N8"	93	12.05	22.0	24.5	1.181	1.680	3.17	29.22	21.0	
5. W. Wilson Bridge	91	12.15	14.0	24.5	1.35	1.90	2.27	29.15	28.5	
6. Broad "N86"	88	12.30	24.0	24.0	1.058	2.20	2.59	29.45	18.0	
7. Piscataway "77"	85	13:30	24.0	23.20	.816	1.80	3.31	26.86	42.0	
15. Nonjemoy F113	52	11.15	24.0	24.80	.377	.150	5.81	18.47	13.5	1.40
15A. Mathias Pt.	47	10.55	33.0	25.90	.351	.210	4.75	18.59	7.5	3.00
16. 301 Bridge "CN"	43	16.17	42.0	15.20	.269	.115	7.85	17.47	6.5	6.60

Readings were taken at midstream
Low Tide Slack Time 13.32

4. IDENTIFICATION OF WATER

In order to determine the areas covered by water it was necessary to first examine some areas where the ground truth was known. Table IV shows the results of the survey.

TABLE IV

AVERAGE RADIANCE FOR DIFFERENT TARGETS IN GRAY LEVELS

BAND	WATER	URBAN AREAS	VEGETATION	MAX. READING
I	25.32	28.68	30.61	127
II	16.96	22.37	25.45	127
III	9.46	27.8	38.5	127
IV	1.33	14.34	22.15	64

Notice that the radiance readings for water was very close to those which Rogers observed for Barton Pond which indicate that probably the same water quality and atmospheric conditions were present. Band III presented the largest contrast between water and its environment and for this reason it was decided to use it to generate a mask. In order to justify this choice the statistical distribution of the radiance of the water and its environment were determined and are shown in Figure III. It can be easily seen that there is no overlap and consequently there was no ambiguity in the determination of the water.

The water can also be identified by using an adaptive technique as follows. First choose an ad hoc threshold slightly above the mean level. Find the water and determine the boundary points. Relax the condition at the boundary points by increasing the threshold by a predetermined amount (e.g. 10%). This has an effect of edge sharpening. This technique was originally tried out and proved to be successful.

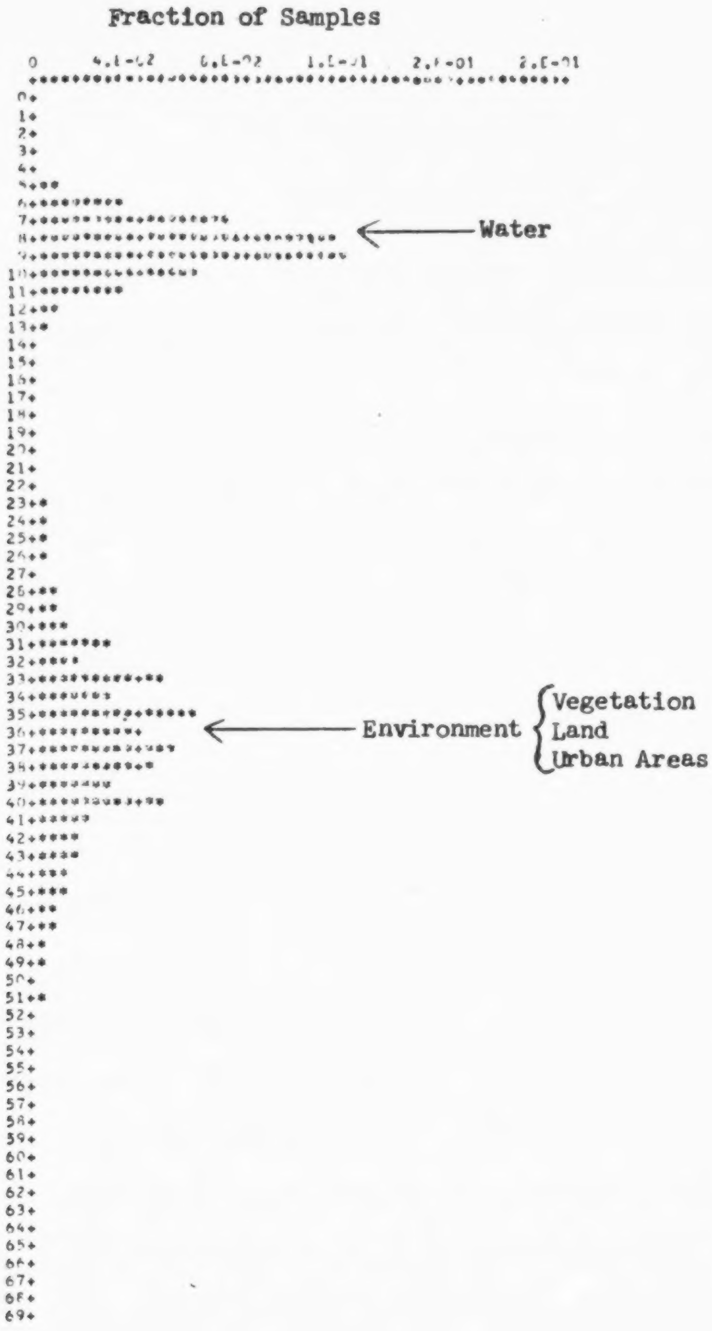


Figure III

Histogram of Brightness of Water and its Environment. Band III.

5. DATA REDUCTION

Once the water has been identified and the appropriate masks have been generated the variations of its brightness are examined. From the statistical distribution of the brightness of all four bands it can be seen that band II shows the maximum spread. The histogram of band II also suggests that three distinct brightness clusters exist. (See figures 4 and 5.) This observation serves as the basis for identifying three classes of water. Those which have high brightness (shown by 0) medium brightness (shown by .) and low brightness (shown by ■). The choice of the thresholds is not obvious. The thresholds were arbitrarily chosen to conform with our best judgment. The results show that with very few exceptions regions of high brightness in band II had high or medium brightness in bands I, II, III. Since band II offered the maximum discrimination it was decided to work with that band alone rather than considering the spectral signature in all four bands

6. INTERPRETATION AND SIGNIFICANCE OF RESULTS

The CCT (Computer Compatible Tapes) offer the maximum possible gray level resolution that can possibly be obtained from the ERTS-1 data. For example in band II the water brightness covers a region of 9 gray levels (out of a max. reading of 128) with approximately an error of 1 to 2%. (Approximately one gray level.) In a photographic product this resolution is greatly reduced the maximum range has been compressed from 128 to 16 gray levels.

In the computer generated thematic maps (figures 4 and 5) areas of high sedimentation content or algae are easily determined because of their high reflectivity and consequently brightness. These areas are the Anacostia river and generally most of the western bank of the Potomac. A number of large Sewage Treatment plants are known to lie in the western bank. These are the Arlington, Alexandria, and Westgate. In the same vicinity lies the largest one, the Blue Plains STP which discharges its effluents underwater midstream. The high sediment areas as predicted from the thematic maps seem to correlate well with the turbidity of the water as indicated by low Secchi Disc measurements and or high chlorophyl concentrations. Although the ground truth measurements were taken 20 days before the satellite overpass it is believed that the conditions were similar (a few hours after high tide with essentially a constant-slope declining river stage) to suggest that the correlation is more substantial than a coincidence. This can be seen in figure 6 which shows the flow conditions of the Potomac River.

From previous published investigations it can be inferred that areas of low reflectivity correspond to clearer water (less sedimentation and algae).

In the thematic maps these areas are shown to be in the vicinity of the 14 St. Bridge and generally the lower eastern bank of the Potomac river. Here again there is qualitative agreement between the ground truth measurements and satellite data. The ground measurements have shown large Secchi Disc depts and low chlorophyl counts in the same areas. An interesting coincidence can be pointed out here; the water of low reflectivity appears to lie in the vicinity of thermal plants. This is true in both the 14 St. Bridge area and Goose Island one where it is known that the Pentagon thermal plant (43 MGD) and the PEPCO generating station (315 MGD) discharge their thermal effluents respectively.

The usefulness of the results lies in the formation of qualitative over all picture of the geographic distribution of pollution in the Potomac river. The most significant observation is that after high tide the pollutants seem to accumulate in the west bank of the river. This phenomenon has been reported before and is attributed to the Coriolis forces.

There is every reason to believe that from the present data quantitative information on water quality can be obtained for water quality surveillance. This, however, can be accomplished with simultaneous spot measurements of ground truth which will calibrate the observational system.

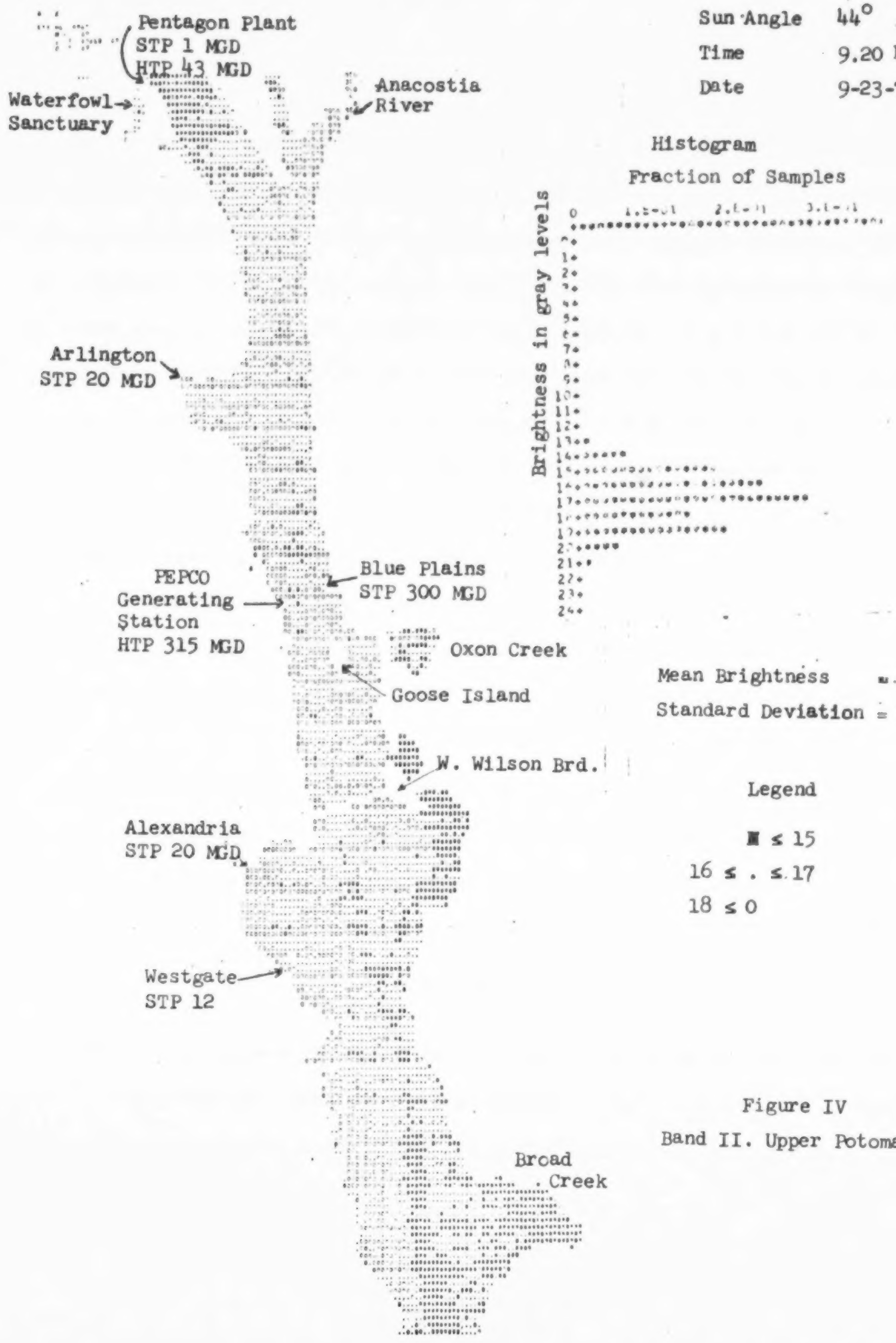
ACKNOWLEDGMENT

We would like to thank Mr. R. Berstein of IBM for providing us with the CCT tapes. We would also like to acknowledge the valuable assistance of N. Melvin of EPA (Region 3) in gathering the ground truth and in the interpretation of results.

Sun Angle 44°

Time 9.20 EST

Date 9-23-72



Mean Brightness = 17.0

Standard Deviation = 1.68

Legend

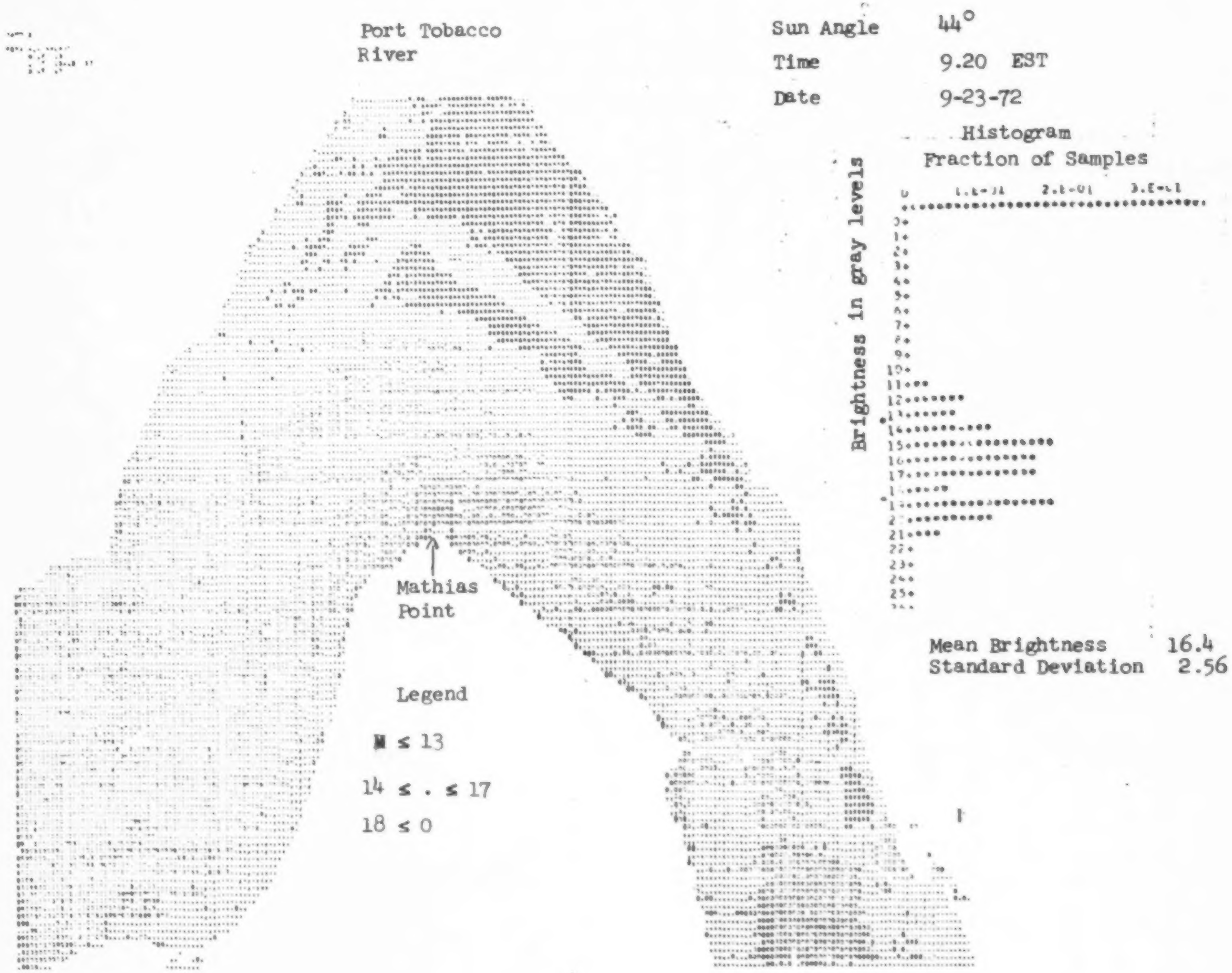
■ ≤ 15

16 ≤ . ≤ 17

18 ≤ 0

Figure IV

Band II. Upper Potomac



Sun Angle 44°

Time 9.20 EST

Date 9-23-72

Mean Brightness 16.4
Standard Deviation 2.56

Figure V
Band II. Mathias Point

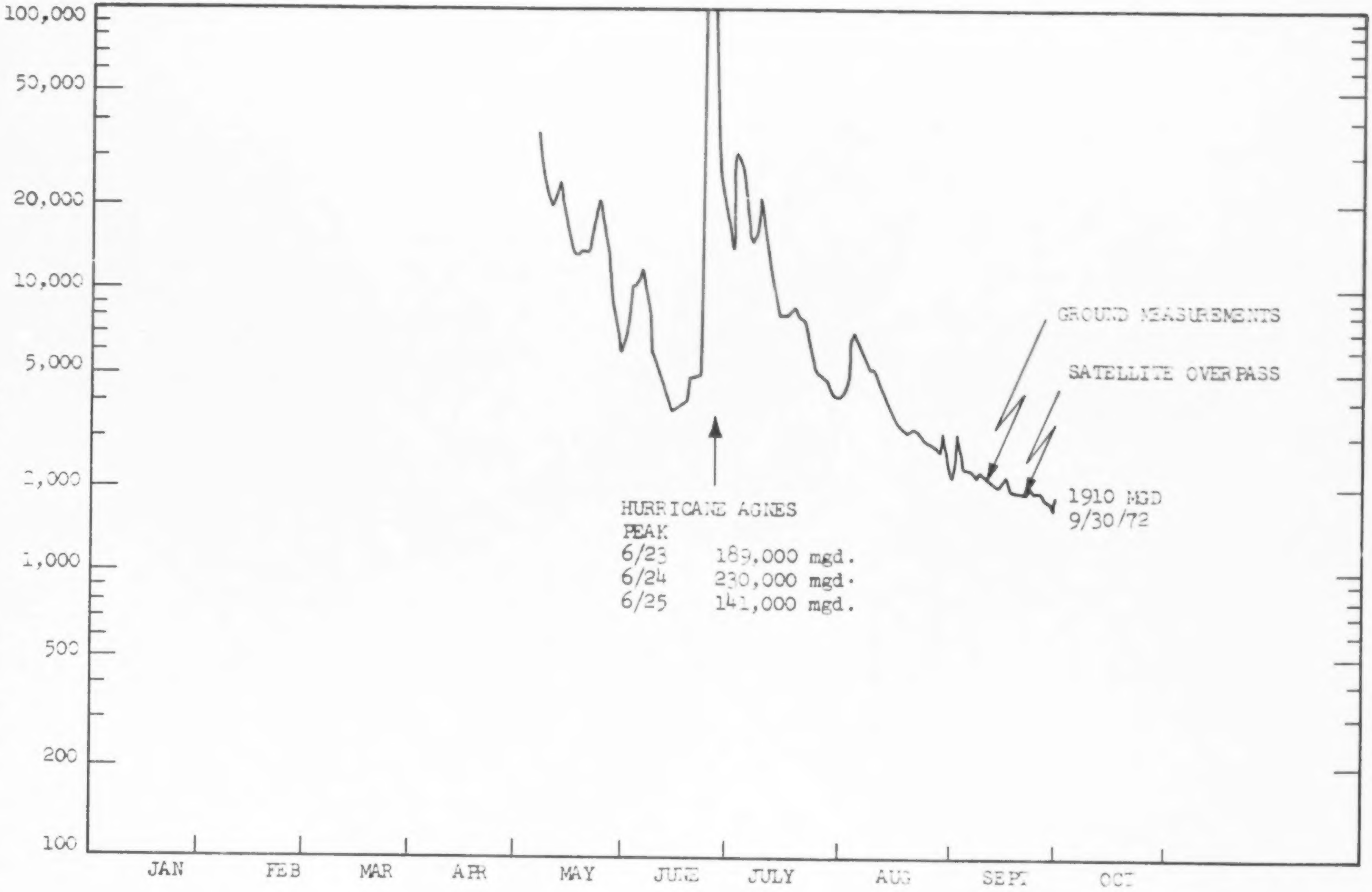


Figure VI

Potomac River Stream Discharge
Near Washington, D. C.

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Satellite Studies of Turbidity, Waste Disposal Plumes and Pollution-Concentrating Water Boundaries

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Abstract

Satellite imagery from four successful ERTS-1 passes over Delaware Bay during different portions of the tidal cycle are interpreted with special emphasis on visibility of turbidity patterns, acid disposal plumes and convergent water boundaries along which high concentrations of pollutants have been detected. The MSS red band (band 5) appears to give the best contrast, although the sediment patterns are represented by only a few neighboring shades of grey. Color density slicing improves the differentiation of turbidity levels. However, color additive enhancements are of limited value since most of the information is in a single color band. The ability of ERTS-1 to present a synoptic view of the turbidity and circulation patterns over the entire bay is shown to be a valuable and unique contribution of ERTS-1 to both coastal ecology and coastal oceanography.

Introduction

The Earth Resources Technology Satellite (ERTS-1) has proven its ability to observe large and inaccessible regions of the earth instantaneously in four spectral bands. However, ERTS-1 must still show it can provide information which is unique or less costly than that attainable by other means, such as aircraft. In the discussion which follows, imagery from four successful ERTS-1 passes over Delaware Bay are interpreted with special emphasis on turbidity, off-shore acid disposal plumes, and boundaries between masses of water having different physical and chemical properties. Attempts to enhance these features, with color-additive techniques and color density slicing are described. The ability of ERTS-1 to present a synoptic view of the turbidity and water boundaries over the entire Delaware Bay region at various stages of the tidal cycle is shown to be a valuable and unique contribution that ERTS-1 is making to coastal ecology and oceanography.

Physical Characteristics of Delaware Bay

The Delaware Bay Estuary is a relatively prominent coastal feature which bounds the Delmarva Peninsula on its northern side. The geography of this region, including the locations of several convenient reference points, is shown in Figure 1. Trenton, New Jersey is generally taken to define the upper limit of the estuary so that its total length is over 130 miles.

Fresh water input to the system is derived mainly from the Delaware River at an average rate of 11,300 cfs which, in terms of volume flow, ranks this as one of the major tributaries on the eastern coastal plain. Together with this large volume of fresh water, the river also discharges a heavy load of suspended and dissolved material, since its effective watershed encompasses an area typified by intensive land use, both agricultural and industrial (Oostdam, 1971). Seaward of the Smyrna River, the bay undergoes a conspicuous exponential increase in both width and cross-sectional area so that the strength of the river flow is rapidly diminished beyond this point. Ketchum (1952) has computed the flushing time of the bay (defined in this case as the time required to replace the total fresh water volume of the bay) to be roughly 100 days. Seasonal variations in river flow cause this figure to fluctuate within a range of from 60 to 120 days. Consequently, river flow is not a significant factor in determining the current pattern in the bay except in the consideration of time-averaged flow. In terms of short period studies, it is mainly important as a source of suspended sediment and contaminants.

The seaward boundary of the bay extends from Cape May southeast to Cape Henlopen, a distance of eleven miles. Tidal flow across this boundary profoundly affects the dynamic and hydrographic features of the entire estuary. The effect is especially pronounced toward the mouth where conditions are generally well mixed. The dynamic behavior of the tides is closely approximated by the cooscillating model described by Harleman (1966). In this model, the upper end of the estuary is assumed to act as an efficient reflecting boundary. Consequently, the actual tidal elevation at any given point is a result of the interaction of both a landward directed wave entering from the ocean and a reflected wave traveling back down the estuary. The tidal range is a maximum at the reflecting boundary and decreases toward the mouth in a manner dependent upon the relative phase of the two components. Observations of the tide at Trenton show a 7-foot range compared to a 4-foot range at the mouth. A relative maximum appears at roughly the location of Egg Island Point, where the phase relationship is temporarily optimal. An important consequence of this behavior is the occurrence of strong reversing tidal currents in the Delaware River. The tidal wavelength as computed by Harleman is 205 miles, so that both peak currents and slack water may occur simultaneously at either end of the bay.

The tidal flow is modified by the bay's rather complex bathymetry (Figure 1). Most prominent are several deep finger-like channels which extend from the mouth into the bay for varying distances (Kraft, 1971). Depths of up to 30 meters are present, making this one of the deepest natural embayments on the east coast. The channels alternate with narrow shoals in a pattern which is shifted noticeably toward the southern shore.

on the northern side, a broad, shallow mud-flat extends from Cape May to Egg Island Point. Considerable transverse tidal shears result from these radical variations in bottom contours. As a consequence, a marked gradient structure may form normal to the main axis of the bay as a function of tidal phase. This intrinsic two-dimensional character, together with the complex, super-imposed time variations, represents an almost insurmountable task when it is confronted with the tools of conventional hydrographic surveys. The problem is ready-made, however, for the techniques of high-altitude photography.

ERTS-1 Imagery

ERTS-1 passes every eighteen days over Delaware Bay at an altitude of about 500 miles, imaging the area with a Multispectral Scanner (MSS). The MSS has four spectral bands as follows: band 4 (0.5 - 0.6 microns), band 5 (0.6 - 0.7 microns), band 6 (0.7 - 0.8 microns), and band 7 (0.8 - 1.1 microns). Since its launch on July 23, 1972, the satellite has made fifteen passes over the Delaware Bay test site, four of which occurred on days with exceptionally good visibility, and produced imagery which is nearly free of clouds and ground haze. The resulting pictures are shown in Figures 2, 3, 4, and 5, consisting of MSS band 5 images taken on October 10 and December 3, in 1972, and on January 26 and February 13 in 1973. (NASA-ERTS-1 I.D. Nos. 1079-15133, 1133-15141, 1187-15140, and 1205-15141 respectively.) Each time, the images were taken at about 15:14 G.M.T. or 10:14 a.m. local time, resulting in low solar altitudes from 23° to 39°, a condition favoring visibility of water features by avoiding sunlight directly reflected off the water surface. Bands 4 and 6 of the October 10th frame are shown for comparison in Figure 2

Optical Properties of Suspended Sediments

Extensive investigations of suspended sediments in Delaware Bay and laser transmission tests in a test tank facility have been conducted respectively by (Oostdam, 1970) and Hickman, 1972). The results can be summarized as follows:

- suspended sediments in Delaware Bay averaged 30 ppm. During July-August the average sediment level was 18 ppm.
- turbidity increased with depth in the water column, except during periods of bloom, when surface turbidities at times exceeded those at greater depths.
- suspended sediment concentration gradients were greater during ebb than during flood because of greater turbulence and better mixing during flood stage.
- the turbidity decreased from winter to summer.
- marked increases in turbidity which were observed during May and September were caused mainly by plankton blooms.
- suspended sediments were silt-clay sized particles with mean diameters around 1.5 microns.
- the predominant clay minerals are chlorite, illite and kaolinite.
- reflectivities for the Delaware Bay sediments were measured to be about 10%.

At the time of the ERTS-1 overpasses, Secci depth readings ranged from about 0.2 meters near the shore up to about 2 meters in the deep channel. Preliminary "equivalent Secci depth" measurements with green and red boards indicated that neither "color" exceeded the readings obtained with the white Secci disc. Therefore it is quite unlikely that the bottom will be visible in any of the ERTS-1 channels and, at least in Delaware Bay, most of the visible features will be caused by light reflected off the surface or backscattered from suspended matter.

"Red" filters, such as the Kodak Wratten No. 25A, have frequently been used in aerial photography to enhance suspended sediment patterns (Klemas et al., 1973, Bowker et al., 1973). In Delaware Bay red filters have been particularly effective for discriminating light-brown sediment-laden water in shallow areas from the less turbid dark-green water in the deep channel. For comparison, photographs taken by a U-2 plane in the green, red and near-infrared bands during the December 3, 1972, ERTS-1 overpass are shown in Figure 6. Note that even from 65,000 feet altitude, suspended sediment patterns photographed in the green band result in poorer contrast than the imagery obtained with a red filter.

To the ERTS-1 Multispectral Scanner suspended sediment patterns also appear most distinct in band 5, the "red" channel, in agreement with aircraft results. Band 4 displays a more complex pattern of suspended matter, which is further aggravated by a masking effect resembling scattering by the atmosphere or haze. Due to its limited water penetration, the band 6 picture shows only weak patterns of suspended sediment near the surface.

Figure 7 contains microdensitometer scans between Cape Henlopen and Cape May at the mouth of the bay. ERTS-1 images taken in bands 4, 5, and 6 were scanned, and grey scales equalized, to enable comparison on the same set of coordinate axes. Although suspended sediment is most clearly visible in MSS band 5, the sediment patterns are caused by only three to four neighboring shades of grey. In agreement with other investigators (Ruggles, 1973 and Bowker et al., 1973), we found that when the sought features were in the first few steps of the grey scale, it was best to use the negative transparencies. When the analysis was performed above the first few steps of the grey scale, positive transparencies proved somewhat more useful.

Turbidity, salinity, temperature and sediment concentration have been measured from boats along the same transsect between the capes as the microdensitometer scans. Preliminary comparisons indicate that for the upper one meter of the water column, band 5 (red band) correlates more closely with turbidity and sediment load measured from boats, than either band 4 or band 6.(Figure 8). Consequently, in our discussion of circulation patterns, we will emphasize imagery obtained in band 5.

Suspended Sediment and Circulation Patterns

Since suspended sediment acts as a natural tracer, it is possible to study gross circulation in the surface layers of the bay by employing ERTS-1 imagery and predicted tide and flow conditions. In addition to ERTS-1 pictures, Figures 2, 3, 4, and 5 contain tidal current maps for Delaware Bay. Each ERTS-1 picture is matched to the nearest predicted tidal current map within ± 30 minutes. A closer match was not attempted at this point, since quantitative comparison would require comprehensive current measurements over the entire bay at the time of each satellite overpass -- a feat not attainable with our limited resources. The current charts indicate the hourly directions by arrows, and the velocities of the tidal currents in knots. The Coast and Geodetic Survey made observations of the current from the surface to a maximum depth of 20 feet in compiling these charts.

The satellite picture in Figure 2 was taken two hours after maximum flood at the entrance of Delaware Bay on October 10, 1972. The sediment pattern seems to follow fairly well the predicted current directions. A strong sediment concentration is visible above the shoals near Cape May and in the shallow nearshore waters of the bay. Peak flood velocity is occurring in the upper portion of the bay, delineating sharp shear boundaries along the edges of the deep channel. At the time of this ERTS-1 picture, the wind velocity was 7 to 12 miles per hour from the north.

Figure 3 represents tidal conditions two hours before maximum flood at the mouth of the bay observed by ERTS-1 on January 26, 1973. High water slack is occurring in the upper portion of the bay, resulting in less pronounced boundaries there as compared to Figure 2. The shelf tidal water is not rushing along the deep channel upstream anymore as in Figure 2, but is caught between incipient ebb flow coming down the upper portion of the river and the last phase of flood currents still entering the bay. The sediment plume directions in Figure 4 seem to show flood water overflowing the deep channel and spreading across the shallow areas towards the shore. On the morning of December 3, 1972, there was a steady wind blowing over the bay at 7 to 9 miles per hour from the west.

As shown in Figure 4, on December 3, 1972, ERTS-1 passed over Delaware Bay one hour before maximum ebb at the mouth of the bay. In addition to locally suspended sediment over shallow areas and shoals observed in Figures 2 and 3 plumes of finer particles are seen in Figure 4 parallel to the river flow and exiting from streams and inlets of New Jersey's and Delaware's coastlines. Shear boundaries along the deep channel are still visible in the upper portion of the bay; however, they are beginning to disappear as slack sets in, resembling conditions in Figure 3. U-2 photographs taken from 65,000 feet 41 minutes after the ERTS-1 overpass are shown in Figure 6. The wind was variable in speed and direction. At the time of the overpass, it was from the south at about 4 miles per hour.

The satellite overpass on February 13th, 1973 occurred about one hour after maximum ebb at the capes. The corresponding ERTS-1 image and predicted tidal currents are shown in Figure 5. Strong sediment transport out of the bay in the upper portion of the water column is clearly visible. Sediment boundaries such as the one in Figure 5 are frequently observed near Cape Henlopen. Changes in Secci depth from about 0.5 meters to 1.1 meters were observed from boats crossing the boundaries toward the less turbid side. The wind velocity at the time of the satellite overpass was about 7 to 9 miles per hour from the north-northwest.

Water Boundaries and Fronts

Boundaries or fronts (regions of high horizontal density gradient with associated horizontal convergence) are a major hydrographic feature in Delaware Bay and in other estuaries. Fronts in Delaware Bay have been investigated using STD sections, dye drops and aerial photography. Horizontal salinity gradients of 4% in one meter and convergence velocities of the order of 0.1m/sec. have been observed. Several varieties of fronts have been seen. Those near the mouth of the bay are associated with the tidal intrusion of shelf water (Figure 9). The formation of fronts in the interior of the bay appears to be associated with velocity shears induced by differences in bottom topography with the horizontal density difference across the front influenced by vertical density difference in the deep water portion of the estuary (Kupferman, Klemas, Polis, Szekielda, 1973). Surface slicks and foam collected at frontal covergence zones near boundaries contained concentrations of Cr, Cu, Fe, Hg, Pb, and Zn higher by two to four orders of magnitude than concentrations in mean ocean water. (Szekielda, Kupferman, Klemas, Polis, 1972) Figure 10, (Band 5, I.D. Nos. 1024-15073) obtained by ERTS-1 on August 16, 1972 contains several distinct boundaries. The southernmost boundary, as shown in Figure 11 is of particular interest. Since it has frequently been observed from aircraft (Figure 12). At the time of the ERTS-1 overpass, divers operating down to depths of 6 meters noted increases in visibility from about half a meter to two meters as the boundary moved past their position.

Waste Disposal Plumes

Careful examination of the ERTS-1 image of January 25, 1973, shown in Figure 13, disclosed a plume 36 miles east of Cape Henlopen caused apparently by a barge disposing acid wastes. The plume shows up more strongly in the green band than in the red band. Since some acids have a strong green component during dumping and turn slowly more brownish-reddish upon contact with seawater, the ratio of reflectance signatures between the green and red bands may give an indication of how long before the satellite overpass the acid was dumped.

Image Enhancements

Color density slicing and optical additive color viewing techniques were employed to enhance the suspended sediment patterns. Grey tone variations were "sliced" into increments and different colors assigned to each increment by using the Spatial Data Datacolor 703 system at NASA's Goddard Space Flight Center. MSS band 5 clearly contains more density steps than bands 4 and 6. Density slicing emphasizes the difference between tidal conditions on October 10th, 1972, and January 26th, 1973.

Additive color composites of bands 4 and 5 of the October 10th overpass using a photographic process of silver-dye bleaching. This process bleaches out spectral separations of each MSS band to produce the color composite. The additive color rendition is then reproduced on Cibachrome CCT color transparencies. Comparison of the composite with the equivalent band 5 image indicated that the composite does not contain more suspended sediment detail than the individual band 5 image. For similar reasons, composites prepared with the International Imaging Systems Mini-Addco Additive Color Viewer, Model 6030 did not improve contrast beyond what was attainable in band 5 directly.

(The color composites could not be included in this report. Interested parties should contact the author).

Acknowledgements

This project is partly funded through ONR Geography Programs, Contract No. N00014-69-A0407; and NASA-ERTS-1, Contract No. NAS5-21837.

Conclusions

a) ERTS is a suitable platform for observing suspended sediment patterns and water masses synoptically over large areas.

b) Suspended sediment acts as a natural tracer allowing photo-interpreters to deduce gross current circulation patterns from ERTS-1 imagery.

c) Under atmospheric conditions encountered along the East Coast of the United States MSS band 5 seems to give the best representation of sediment load in the upper one meter of the water column. Band 4 is masked by haze-like noise, while band 6 does not penetrate sufficiently into the water column.

d) In the ERTS-1 imagery the sediment patterns are delineated by only three to four neighboring shades of grey.

e) Negative transparencies of the ERTS-1 images give better contrast whenever the suspended sediment tones fall within the first few steps of the grey scale. Considerable improvement in contrast can be obtained by more careful development of film and prints.

f) Color density slicing helps delineate the suspended sediment patterns more clearly and differentiate turbidity levels.

g) Sediment pattern enhancements obtained by additive color viewing of the four ERTS-1 MSS bands did not noticeably improve the contrast above that seen in the best band, i.e., MSS band 5.

h) Water boundaries containing high concentrations of toxic substances identified in several of the ERTS-1 frames.

i) ERTS-1 bands 4 and 5 of Oct. 10, 1972, contain a clearly visible acid disposal plume 36 miles east of Cape Henlopen.

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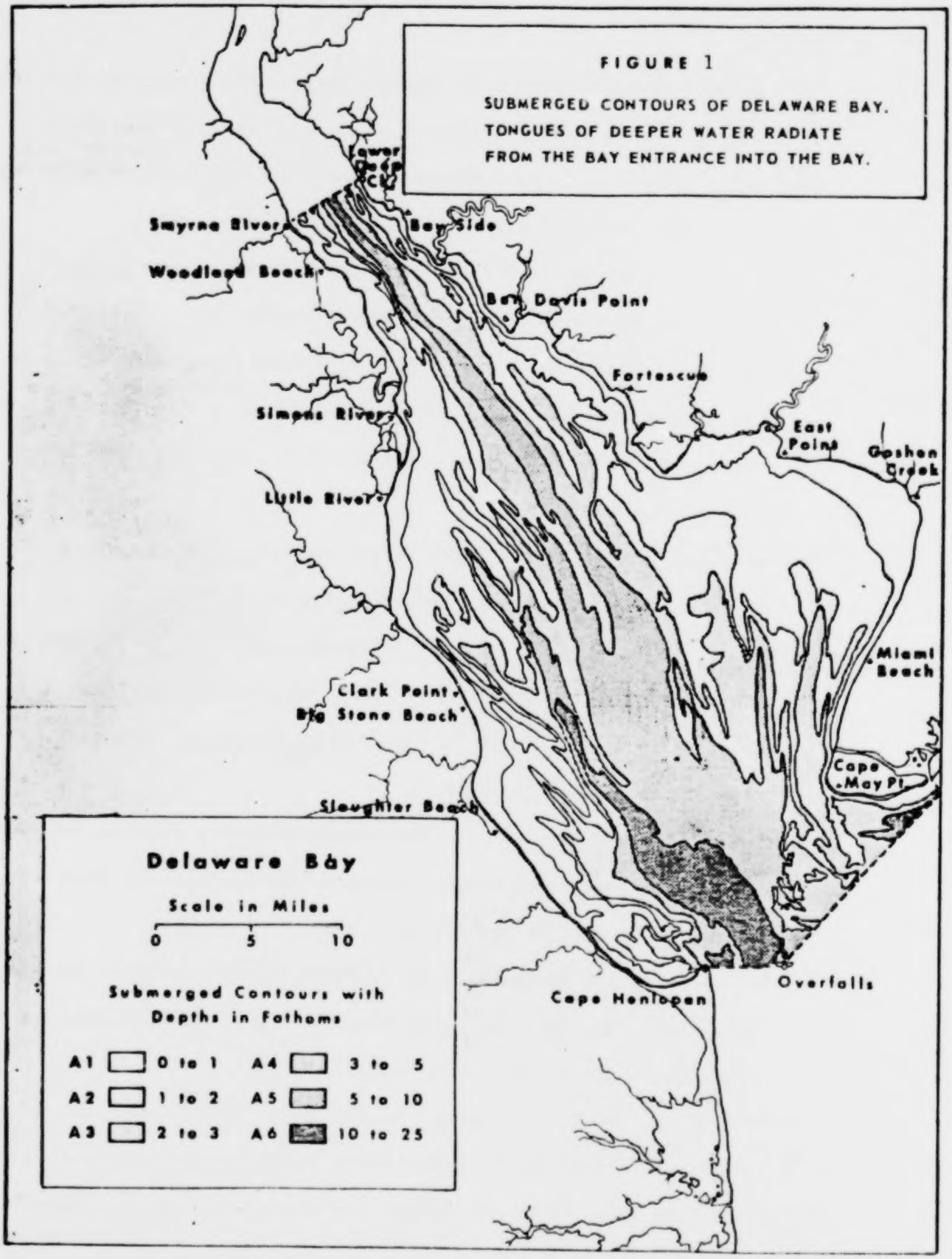


FIGURE 1

SUBMERGED CONTOURS OF DELAWARE BAY. TONGUES OF DEEPER WATER RADIATE FROM THE BAY ENTRANCE INTO THE BAY.

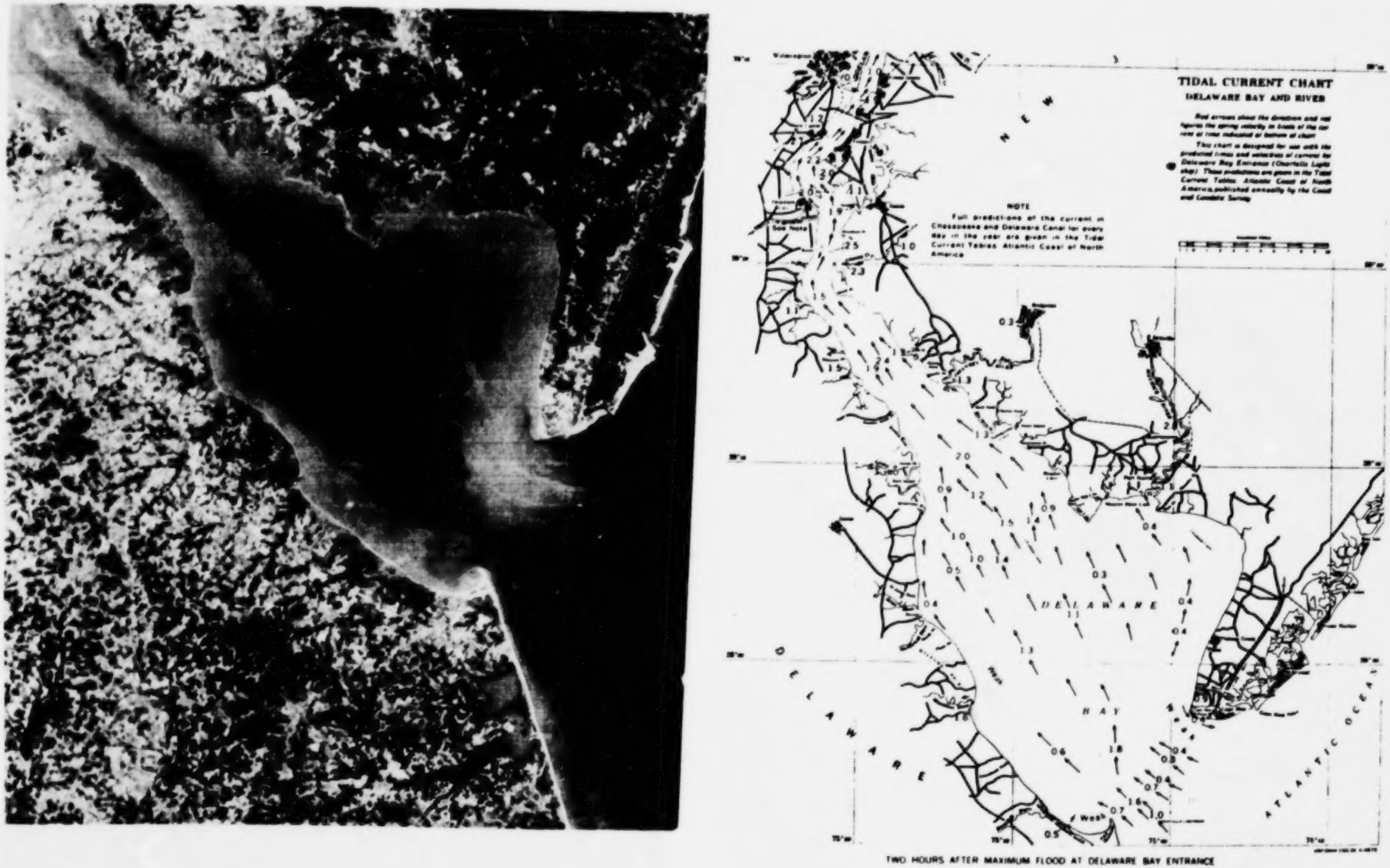

TIDAL CURRENT CHART
DELAWARE BAY AND RIVER
NOTE
Full predictions of the current in Chesapeake and Delaware Canal for every day in the year are given in the Tidal Current Tables Atlantic Coast of North America
N E W
D E L A W A R E
B A Y
D E L A W A R E
ATLANTIC OCEAN
TWO HOURS AFTER MAXIMUM FLOOD AT DELAWARE BAY ENTRANCE

Figure 2 - ERTS-1 image of Delaware Bay obtained in MSS band 5 on October 10, 1972, and tidal current map. (I.D. No. 1079-15133.)

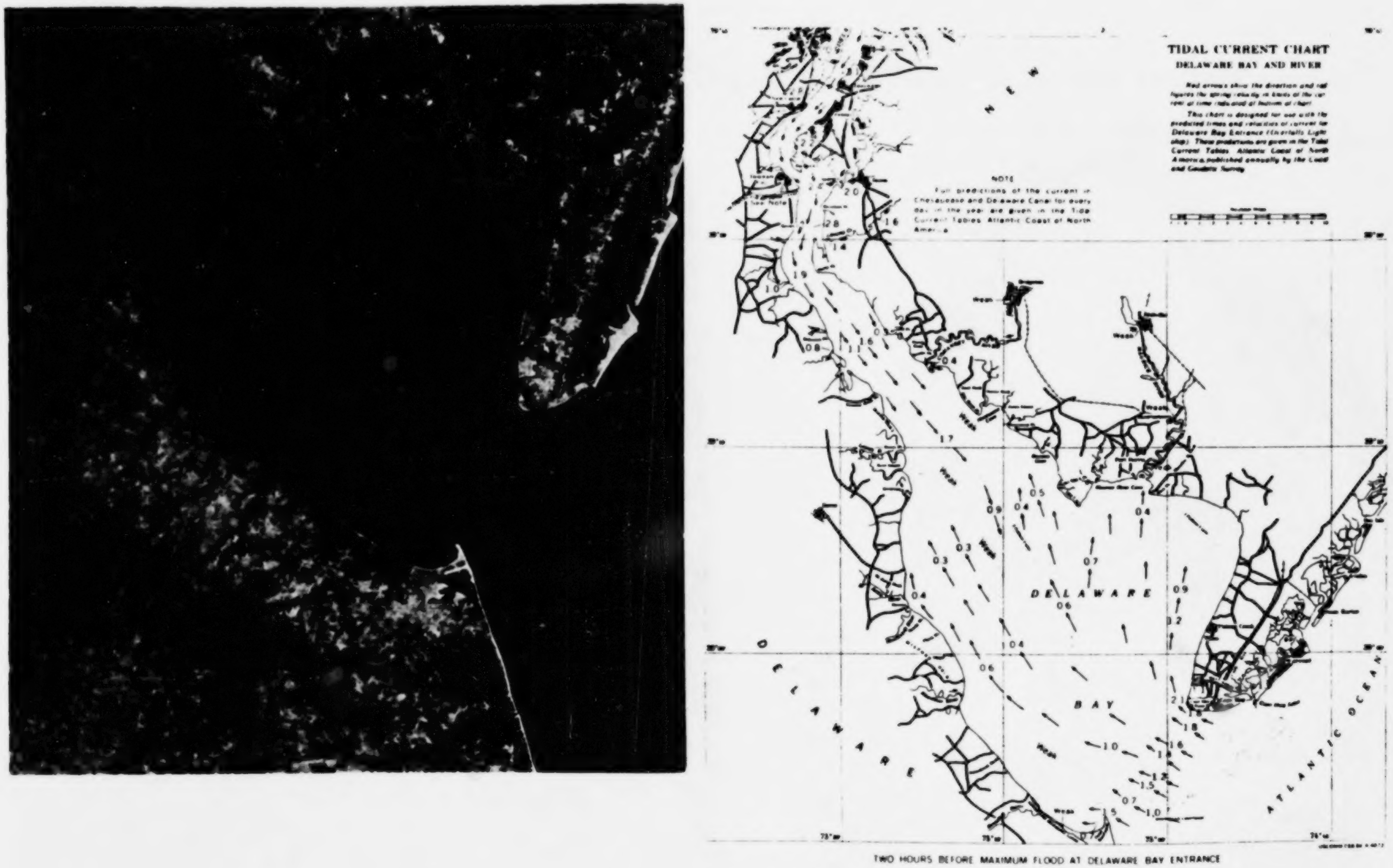

TIDAL CURRENT CHART
DELAWARE BAY AND RIVER
Red arrows show the direction and red figures the spring velocity in knots of the current at time indicated at bottom of chart
This chart is designed for use with the predicted times and velocities of current for Delaware Bay Entrance (Overfalls Lightship). These predictions are given in the Tidal Current Tables, Atlantic Coast of North America, published annually by the Coast and Geodetic Survey
NOTE
Full predictions of the current in Chesapeake and Delaware Canal for every day in the year are given in the Tide Current Tables Atlantic Coast of North America
NEW
DELAWARE
BAY
DELAWARE
ATLANTIC OCEAN
TWO HOURS BEFORE MAXIMUM FLOOD AT DELAWARE BAY ENTRANCE

Figure 3 - ERTS-1 image of Delaware Bay obtained in MSS band 5 on January 26, 1973, and tidal current map. (I.D. Nos. 1187-15140).

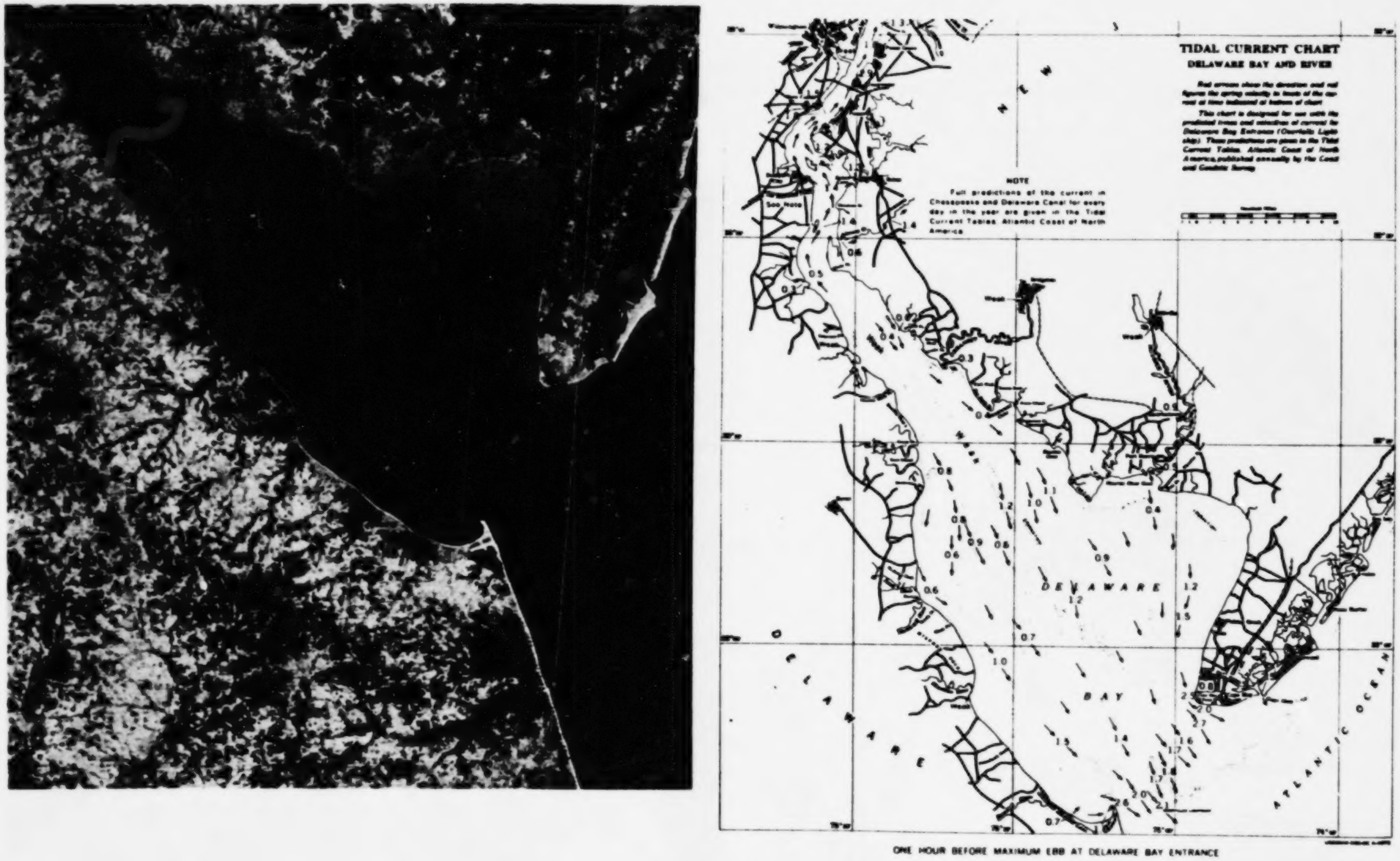

TIDAL CURRENT CHART
DELAWARE BAY AND RIVER
NOTE
Full predictions of the current in Chesapeake and Delaware Canal for every day in the year are given in the Tidal Current Tables, Atlantic Coast of North America.
NEW
DELAWARE
BAY
DELAWARE
ATLANTIC OCEAN
ONE HOUR BEFORE MAXIMUM EBB AT DELAWARE BAY ENTRANCE

Figure 4

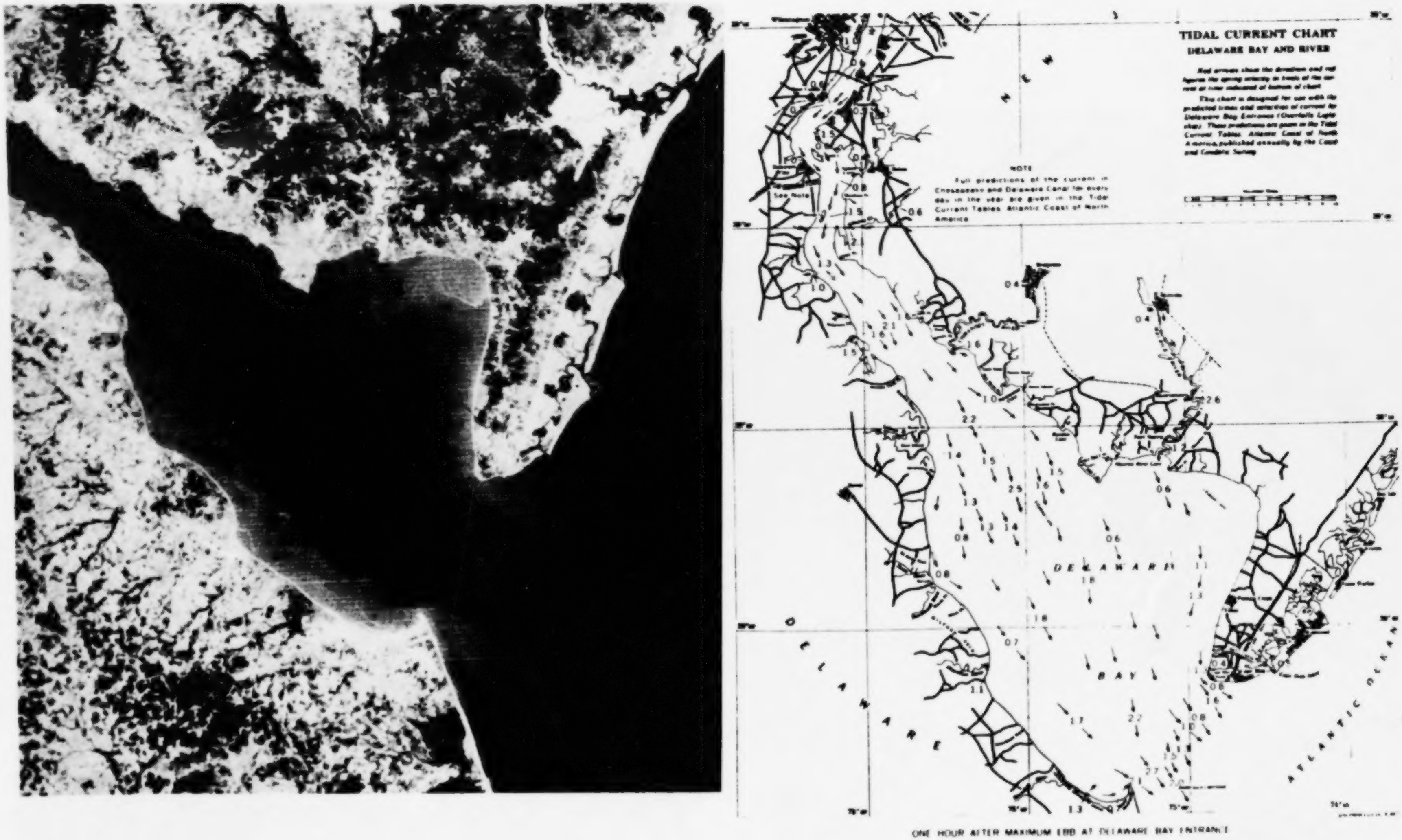
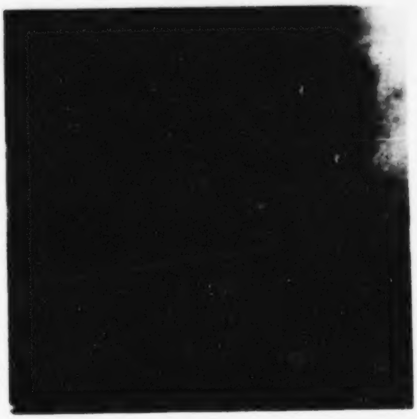
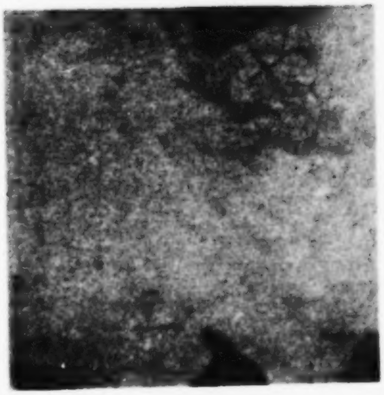

TIDAL CURRENT CHART
DELAWARE BAY AND RIVER
NOTE
Full predictions of the current in Chesapeake and Delaware Canal for every day in the year are given in the Tidal Current Tables, Atlantic Coast of North America
DELAWARE
DELAWARE
BAY
ATLANTIC OCEAN
ONE HOUR AFTER MAXIMUM EBB AT DELAWARE BAY ENTRANCE

Figure 5 - ERTS-1 image of Delaware Bay obtained in MSS band 5 on February 13, 1973, and tidal current maps. (I.D. Nos. 1205-15141).

a) 0.475—0.575 microns.

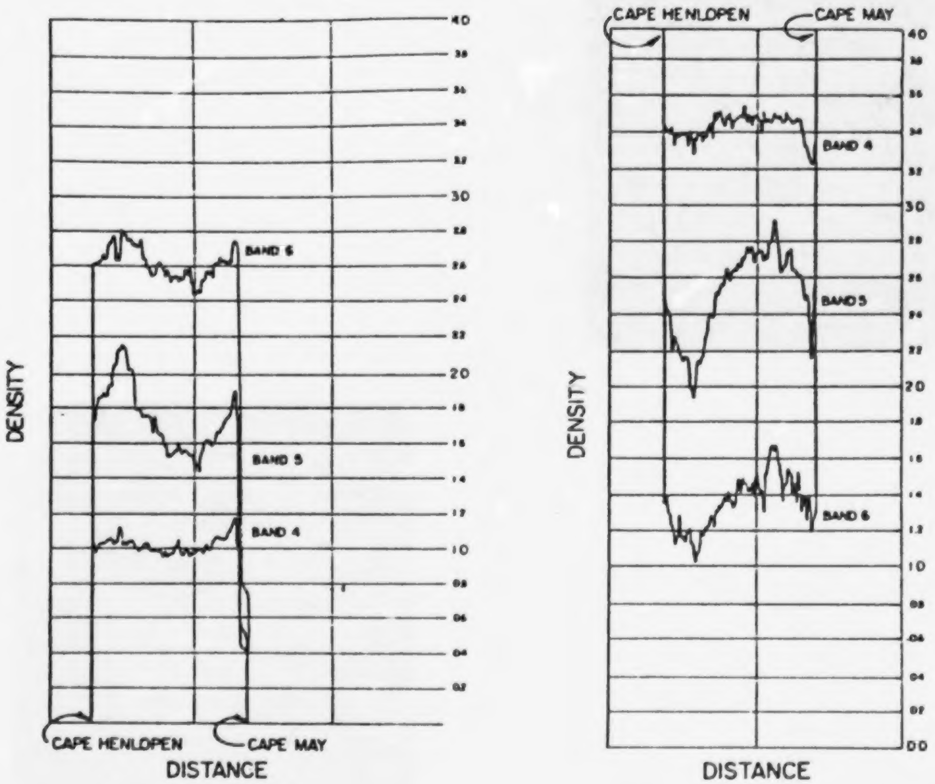


b) 0.580—0.680 microns.



c) 0.690—0.760 microns.

FIG. 6. Photographs taken at 65,000 feet altitude by a NASA U-2 aircraft, 41 minutes after the December 3, 1972 ERTS-1 overpass. The mouth of Delaware Bay is shown in three spectral bands.



Positive transparencies.

Negative transparencies.

FIGURE 7

Microdensitometer traces of October 10, 1972, ERTS-1 imagery from Cape Henlopen, Delaware to Cape May, New Jersey, using MSS bands 4, 5, and 6.

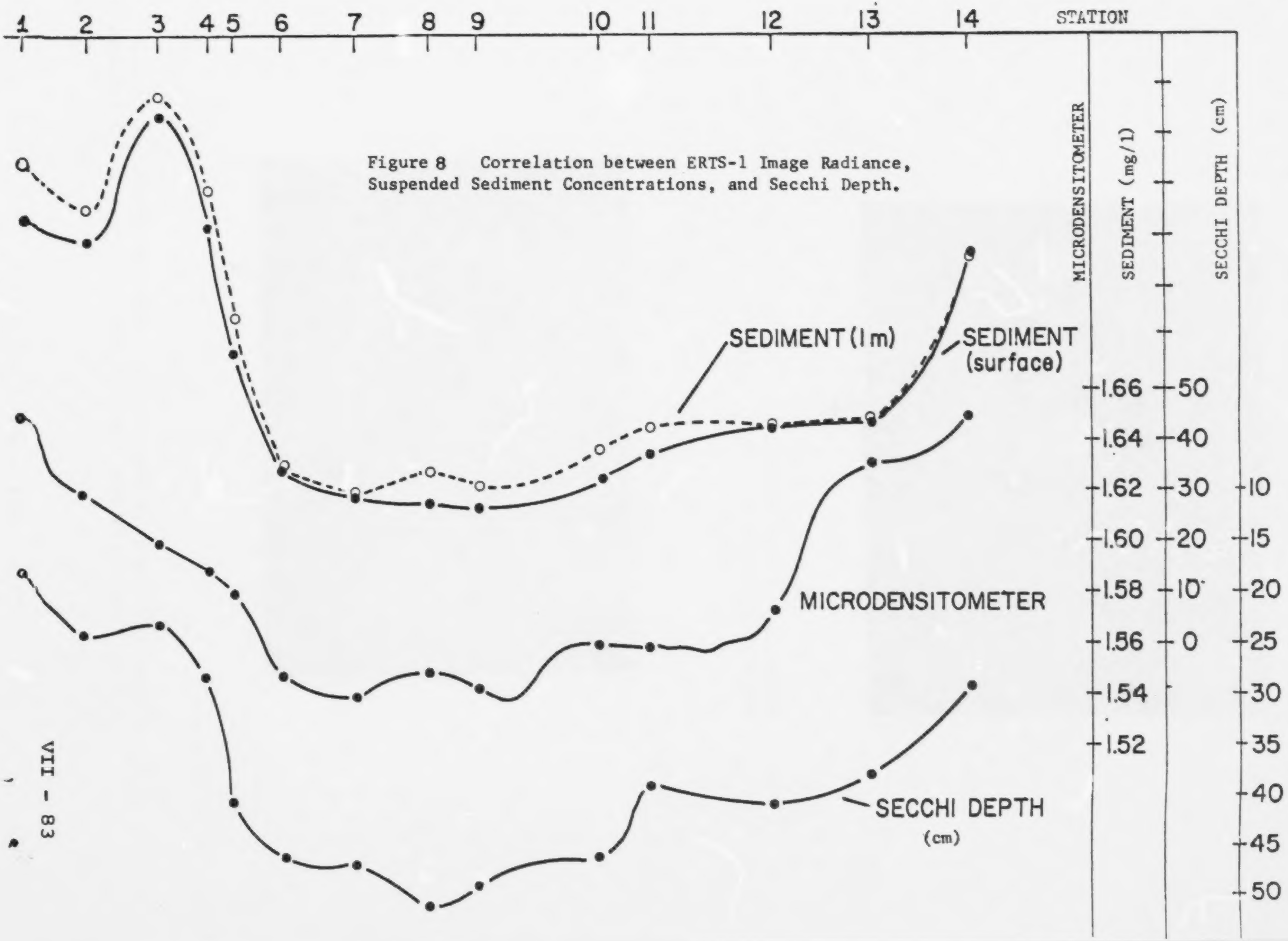


Figure 8 Correlation between ERTS-1 Image Radiance, Suspended Sediment Concentrations, and Secchi Depth.

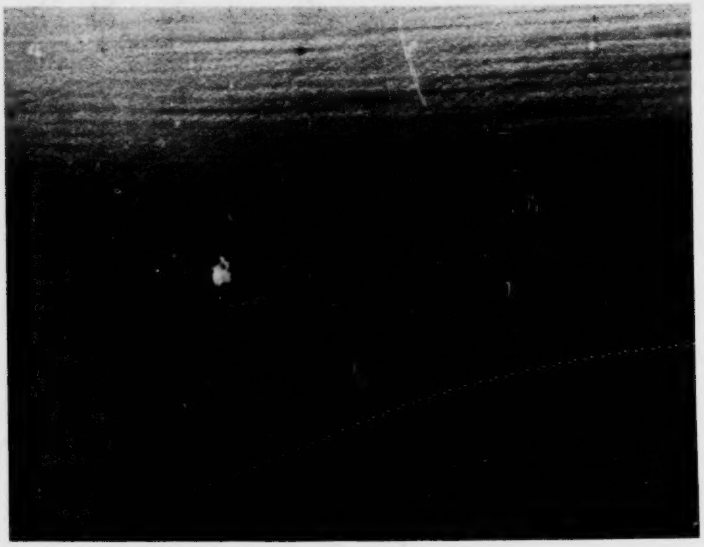


Figure 9 Frontal system caused by higher salinity shelf water intruding into Delaware Bay.

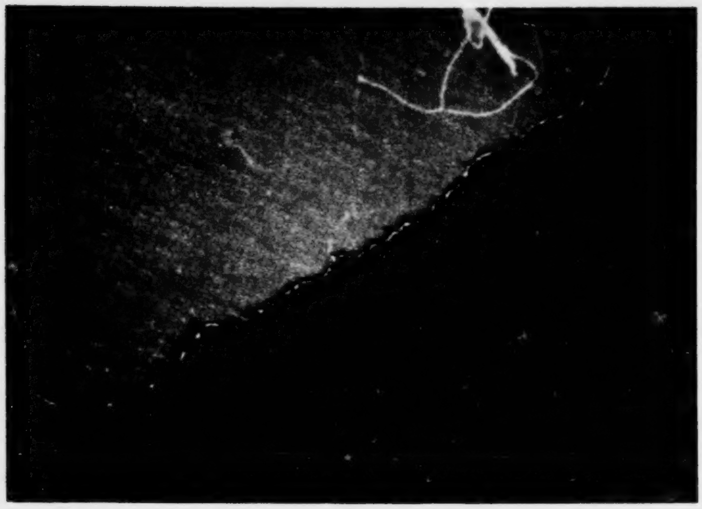


Figure 12 Aerial photograph from 9000 feet altitude of foamline at boundary between two different water masses off Delaware's coast.

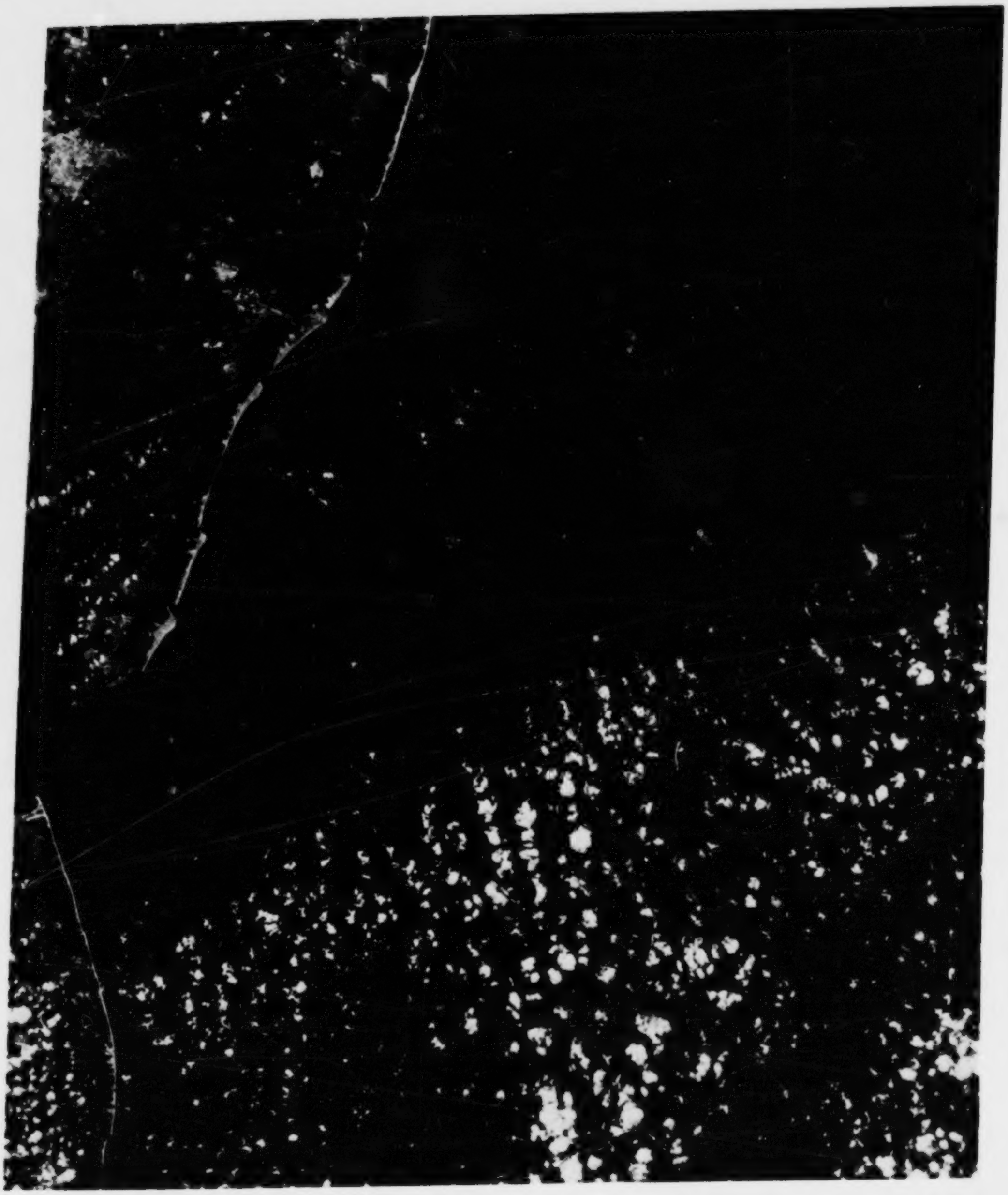


Figure 10 - ERTS-1 image of the mouth of Delaware Bay showing several water mass boundaries and high concentrations of suspended sediment in shallow waters. (Band 5, August 16, 1972, I.D. Nos. 1024-15073).

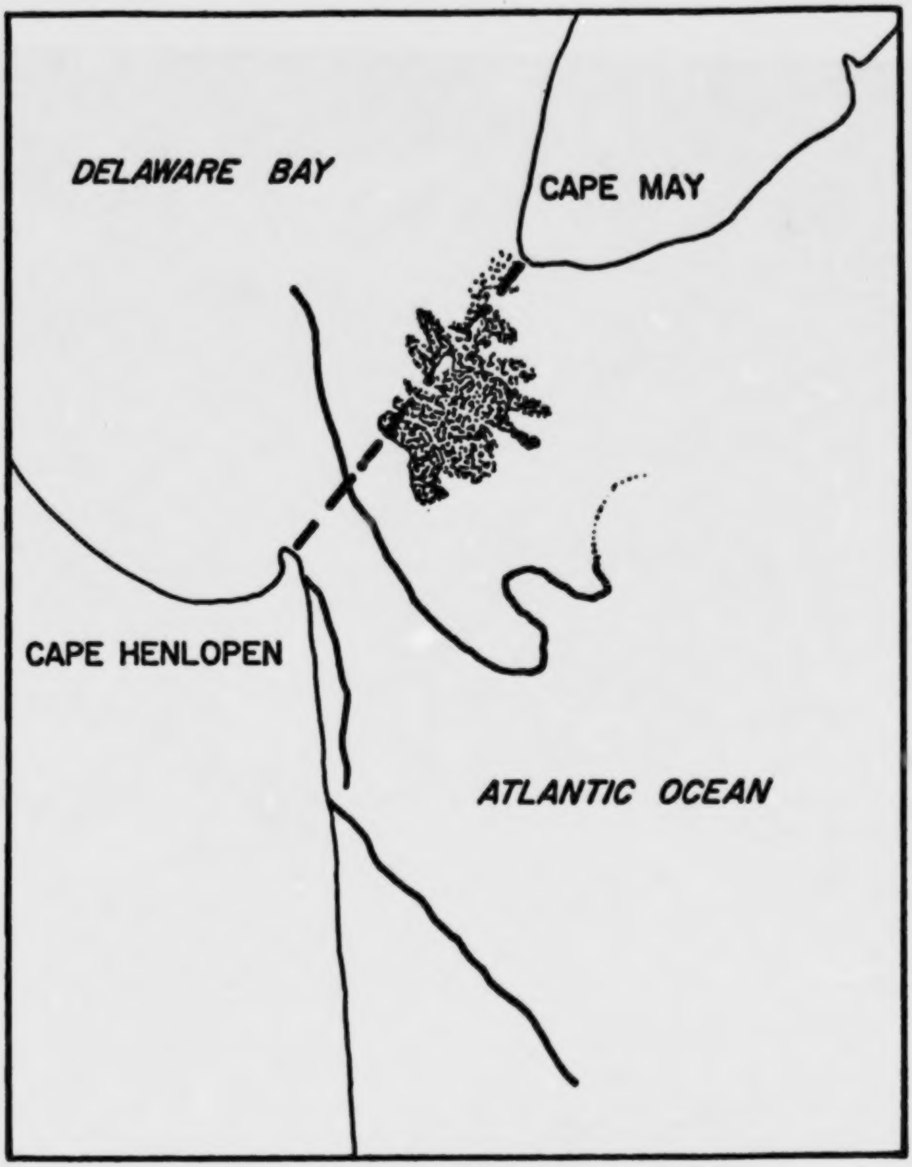


Figure 11 Aquatic boundaries and suspended sediment plumes identified in the ERTS-1 image of August 16, 1972, shown in Figure 14.

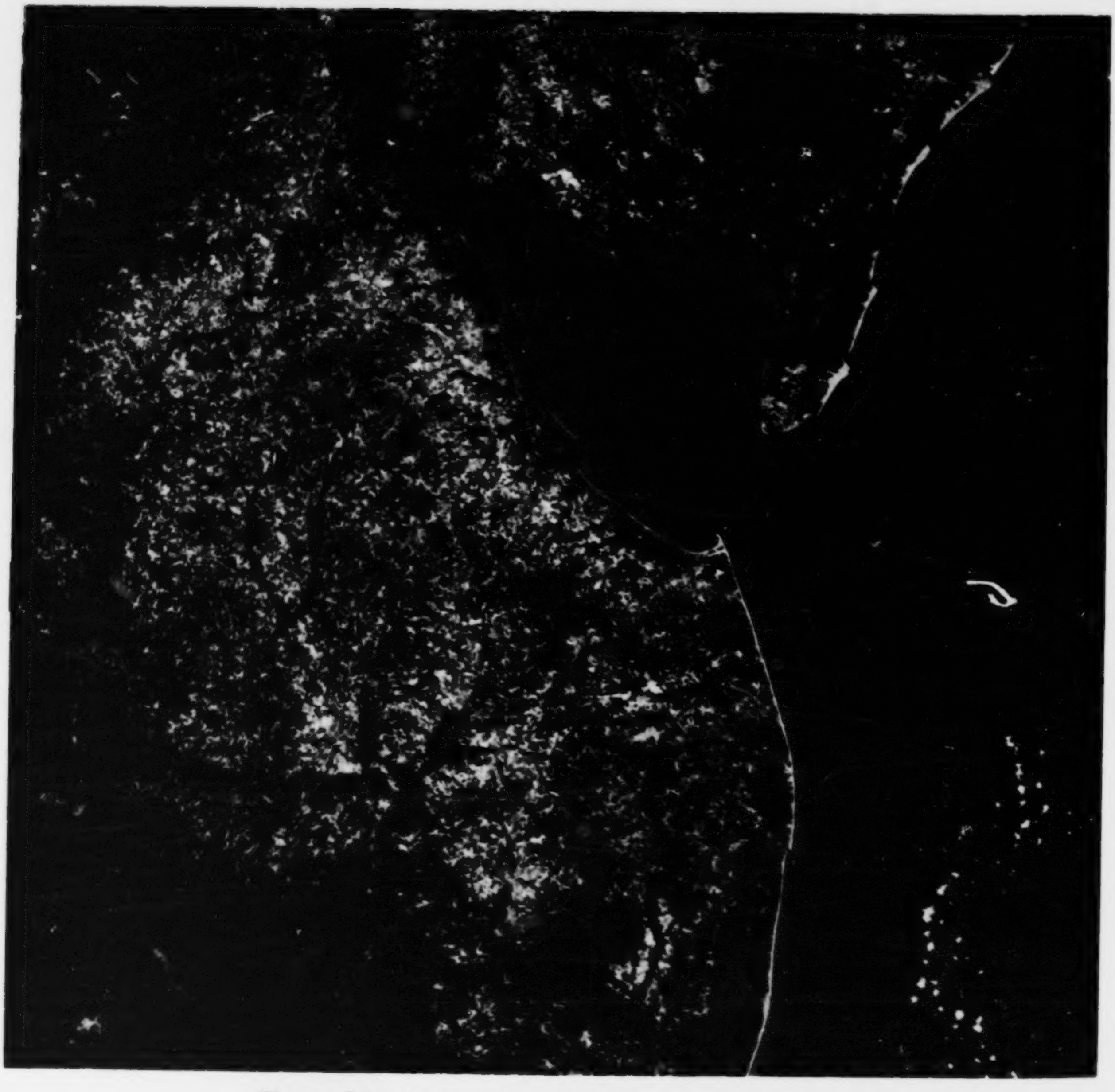


Figure 13 - Acid waste dumped from barge about 40 miles east of Indian River Inlet appears clearly as a fishhook shaped plume in MSS band 4 image of January 25, 1973.

DATA COLLECTION PLATFORMS FOR ENVIRONMENTAL MONITORING

J. Earle Painter
NASA/Goddard Space Flight Center

ABSTRACT

The Earth Resources Technology Satellite (ERTS) Data Collection Platform (DCP) Network is in operation with installations extending from Iceland to Hawaii and from Alaska to Honduras. Thirty investigators have deployed 125 DCP's in twenty-five states and five foreign countries. These installations are used for in-situ monitoring in the areas of meteorology, hydrology, agriculture, vulcanology and water quality. Water quality installations in prototype operational networks are supplying data to regulatory agencies on a daily or more frequent basis. The failure of some installations to perform adequately points out a definite need for further sensor development and improved implementation techniques. The ERTS experiment has demonstrated the feasibility and reliability of space relay systems for automatic collection of data from in-situ environmental sensors and indicates a promise of cost effective operation of such systems.

INTRODUCTION

The Data Collection System (DCS) flown on the Earth Resources Technology Satellite (ERTS) is the first attempt to establish a large scale telemetry network using a satellite to relay data from in-situ environmental sensors to a central collection point. After more than one year of operation, the attempt has proven successful.

SYSTEM DESIGN GOALS

Design goals for the DCS (Table 1) were established by consulting with appropriate personnel in those federal agencies which have environmental monitoring responsibilities. They include reliability, versatility, and low cost as primary requirements. These goals were all met or exceeded by the system during the past 14 months of operation (Table 2).

TABLE 1

ERTS DCS DESIGN GOALS

SYSTEM PARAMETERS

ONE GOOD TRANSMISSION EVERY TWELVE HOURS

LOW ERROR RATE

RAPID DATA DELIVERY

VERSATILE TRANSMISSION FORMAT

GOOD RADIOINTERFERENCE IMMUNITY

PLATFORM (TRANSMITTER) PARAMETERS

LOW COST

LOW POWER REQUIREMENTS

RELIABLE OPERATION

VERSATILE SENSOR INTERFACE

TABLE 2

ERTS DCS PERFORMANCE

SYSTEM PARAMETERS

GOOD TRANSMISSIONS EACH TWELVE HOURS	6 to 8
ERROR RATE (TO USER)	$< 10^{-5}$
DATA DELIVERY (TELETYPE)	30 MINUTES
TRANSMISSION FORMAT	SATISFIES USERS
RADIOFREQUENCY IMMUNITY	EXCELLENT

PLATFORM (TRANSMITTER) PARAMETERS

COST (200 UNIT PROCUREMENT)	$2,500
POWER DISSIPATION	50 MILLIWATTS
FAILURE RATE	2% PER MONTH
SENSOR INTERFACE VERSATILITY	SATISFIES USERS

SYSTEM DESCRIPTION

The system (Fig. 1) consists of a data formatting and transmitting unit, called the Data Collection Platform (DCP), a receiver and a retransmitter aboard ERTS-1; and receiving, demodulating and decoding equipment located at the Goldstone, California and Goddard data acquisition stations. Data is transmitted from the data acquisition stations to the ERTS Control Center at Goddard, then to the NASA (ERTS) Data Processing Facility (NDPF) where it is processed and distributed to Users.

Every three minutes a sample of data from each of as many as eight sensors is accepted by the DCP in either analog or digital form. The DCP converts the analog data to digital form, adds a DCP identification number, encodes the data for error control purposes, and transmits it skyward. If the spacecraft is in range of both the DCP and one of the receive sites, the data is received and retransmitted by the spacecraft and received by the ground station where it is demodulated, decoded and forwarded to the ERTS Operations Control Center (OCC) at Goddard.

In the Control Center, the DCS data is screened for quality and retransmitted to Users by teletype.

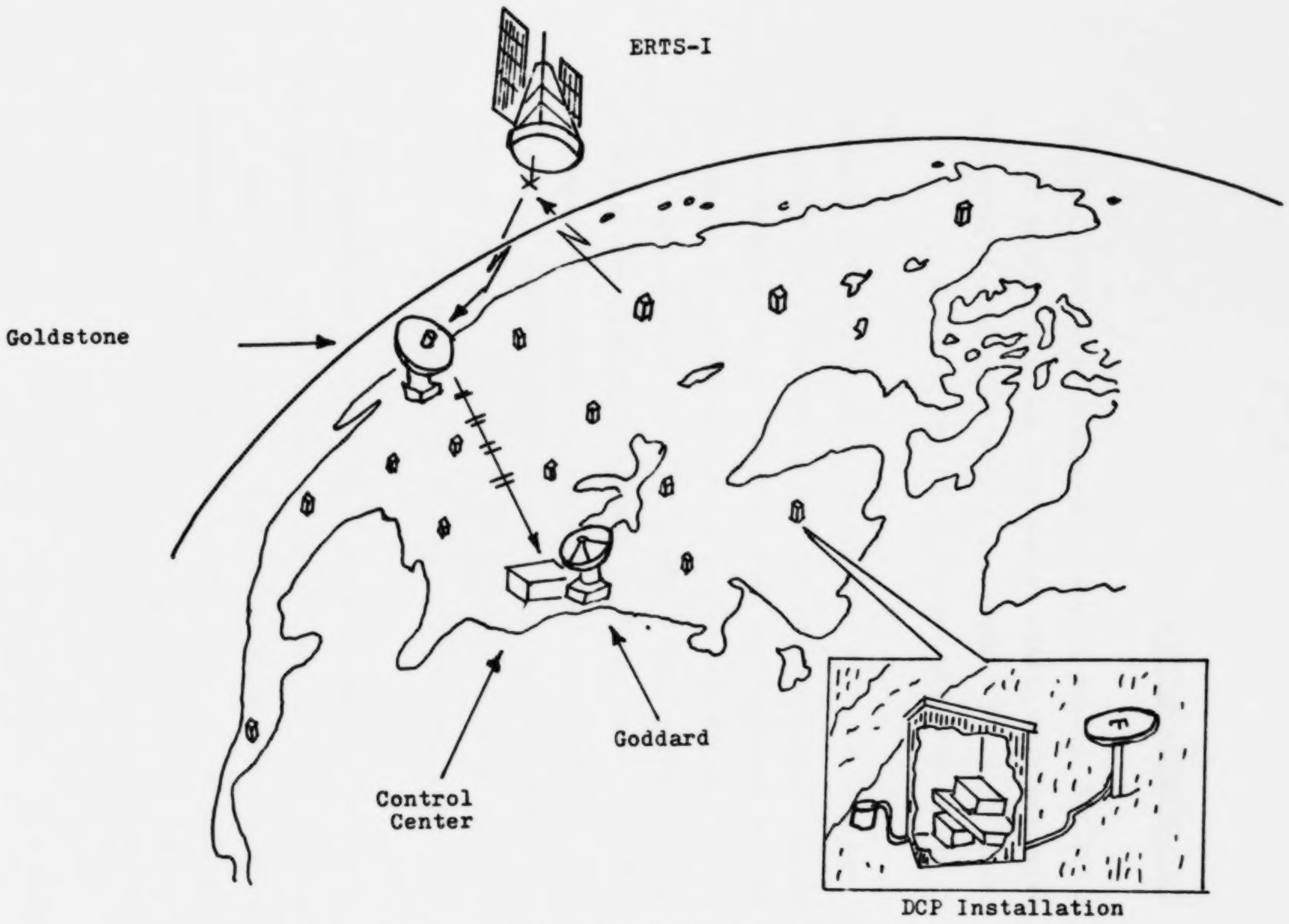


Fig. 1 ERTS DATA COLLECTION SYSTEM

THE OPERATING NETWORK

A 125 DCP network is now in operation with installations extending from Alaska to Honduras and from Iceland to Hawaii (Fig. 2). DCP's are transmitting from locations in 22 states and five foreign countries (Table 3).

A total of 29 Users are currently involved in the program (Table 4) representing six federal agencies, one state, one foreign country, four universities, and one industrial firm. These investigators are using the system for eight major application categories (Table 5). The most active organization is the U. S. Geological Survey, accounting for one-third the Users and one-half the DCP's. Hydrology is the primary application. Volcanology is second closely followed by water quality. Table 6 is a partial list of parameters monitored by the DCS installations.

An individual DCP in the network is contacted during two to seven orbits per day, depending upon location (latitude and proximity to a data acquisition station). One to four messages are received during each contact period averaging 17 good messages per day.

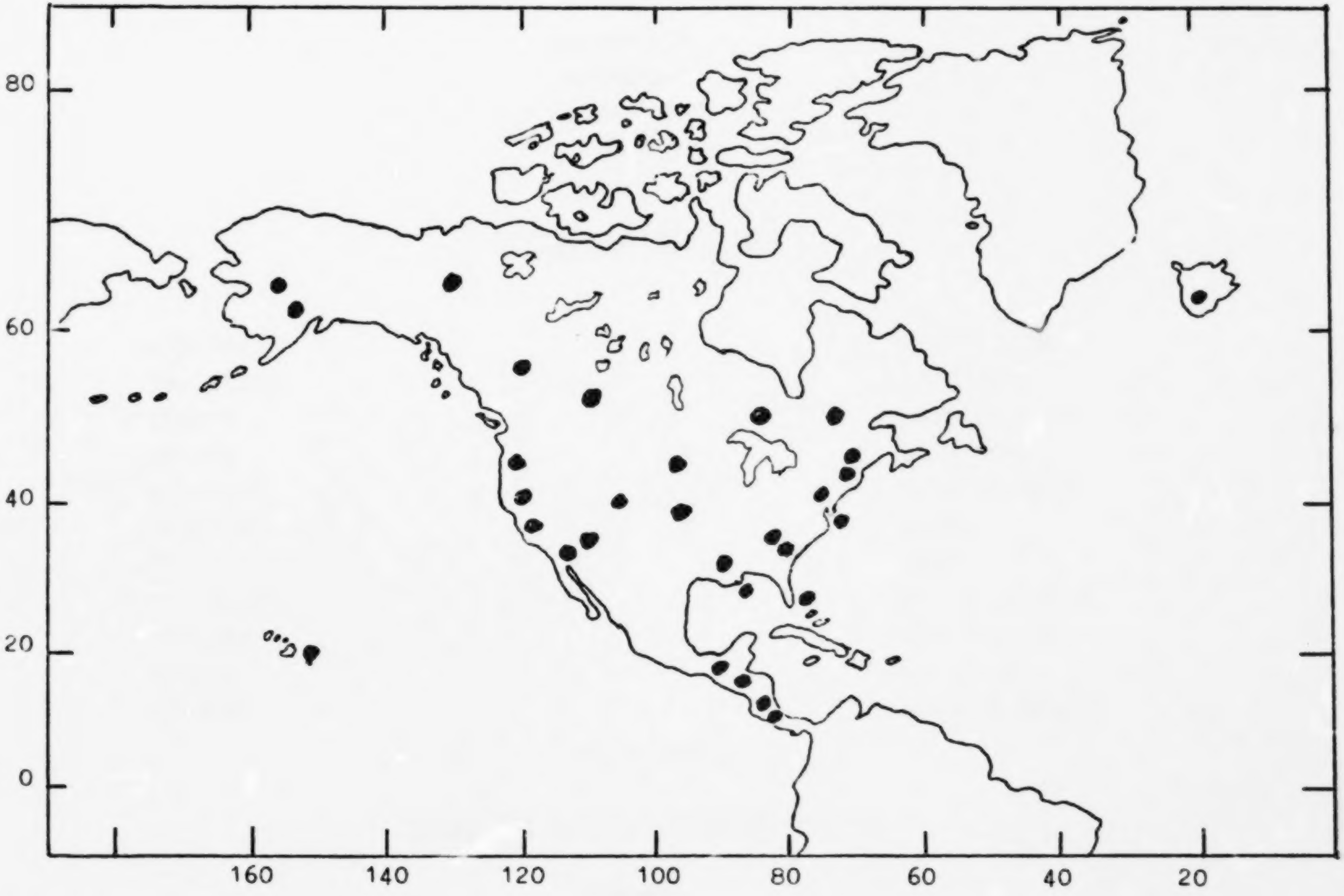


Fig. 2 ERTS-1 DCP NETWORK

TABLE 3

GENERAL LOCATION OF ERTS-1 DCP'S

22 STATES

ALABAMA
ALASKA
ARIZONA
CALIFORNIA
CONNECTICUT
DELAWARE
FLORIDA
HAWAII
KANSAS
LOUISIANA
MARYLAND
MASSACHUSETTS
MICHIGAN
MISSISSIPPI
NEW HAMPSHIRE
OHIO
OREGON
PENNSYLVANIA
TENNESSEE
VERMONT
VIRGINIA
WASHINGTON

5 FOREIGN COUNTRIES

CANADA
EL SALVADOR
GUATEMALA
ICELAND
NICARAGUA

TABLE 4

ORGANIZATIONS USING ERTS-1 DCS

ORGANIZATION	NO. INVESTIGATORS	ASSIGNED DCP'S	ACTIVE DCP'S
FOREIGN (CANADA)	6	14	12
U.S. GEOLOGICAL SURVEY	10	106	58
BUREAU OF LAND MGMT.	1	8	3
FORESTRY SERVICE	1	3	3
CORPS OF ENGINEERS	1	30	21
NAVOCEANO	1	3	0
UNIVERSITIES	4	18	3
STATES	1	1	1
NASA	3	29	4
INDUSTRY	1	2	1
TOTALS	29	214	106

TABLE 5

USE OF ERTS-1 DCS BY APPLICATION

APPLICATION	NO. OF USERS	DCP'S ASSIGNED
METEOROLOGY	5	10
HYDROLOGY	20	75
WATER QUALITY	4	26
OCEANOGRAPHY	3	9
FORESTRY	1	3
AGRICULTURE	1	3
VOLCANOLOGY	2	33
ARCTIC ENVIRONMENTS	1	2

TABLE 6

PARAMETERS MONITORED BY ERTS-1 DCS

RESERVOIR LEVEL
STREAM FLOW
GROUND WATER
TIDAL VARIATION
ICE CONDITIONS
SALINITY
DISSOLVED OXYGEN
TURBIDITY
ACIDITY-ALKALINITY
BIOLOGICAL CONTENT
WATER TEMPERATURE
AIR TEMPERATURE
WIND DIRECTION
WINDSPEED
HUMIDITY
PRECIPITATION
SOLAR RADIATION
SNOW DEPTH
SNOW WATER CONTENT
EVAPORATION
SOIL MOISTURE
EARTH TILT
TREMOR EVENTS
EARTH TEMPERATURES

WATER QUALITY INSTALLATIONS

The ERTS DCS installations of most acute interest to regulatory agencies are those which monitor water quality parameters. Several organizations are using such installations with mixed results.

DELAWARE BASIN WATER QUALITY NETWORK

The U. S. Geological Survey, Water Resources Division, Pennsylvania District operates a network of twelve water quality installations in the Delaware River Basin using ERTS to relay the data (Fig. 3). These data are relayed through ERTS-1 to Goddard Space Center, then forwarded via teletype to the USGS offices in Harrisburg, Pennsylvania, where they are processed and distributed daily to the Delaware River Basin Commission and other regulatory agencies.

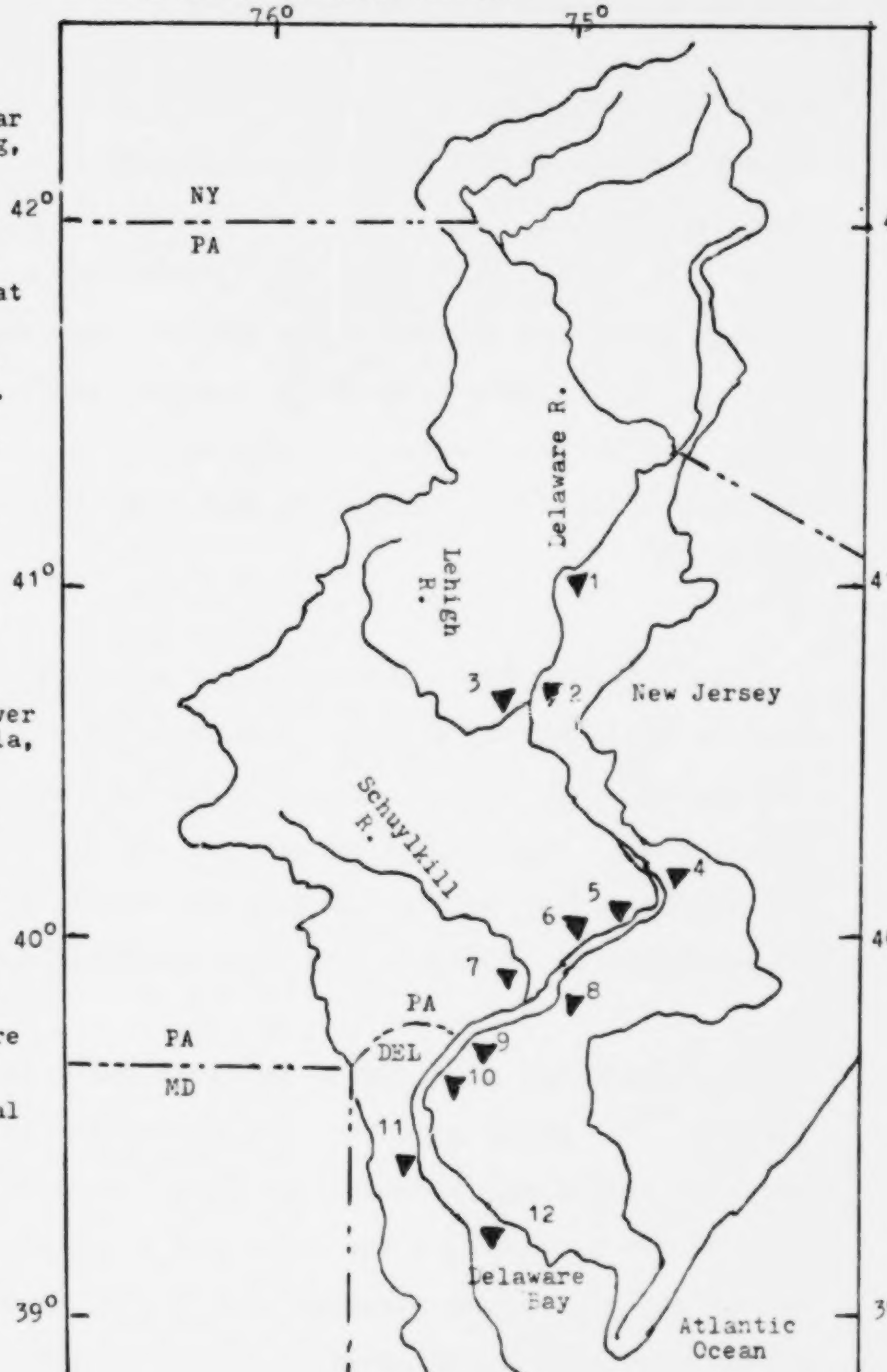
All the Delaware Basin Installations are single line pumping configurations with a submerged pump located in a stream-side well and an instrumentation assembly in a nearby shed. Equipment from several manufacturers is used and includes four sensors in each installation to monitor temperature, pH, conductivity, and dissolved oxygen.

Thermocouples are used for temperature and give little trouble. The glass pH probe with associated reference probe are also relatively trouble free once installed properly. Most sensor problems in the array are a result of coating of the one mil teflon membrane in the D.O. monitor and the presence of conducting material on and around the four probe conductivity sensor.

Fig. 3 ERTS DATA RELAY

DELAWARE RIVER BASIN NETWORK

1. Del. River near E. Stroudsburg, PA.
2. Del. River at Easton. PA
3. Lehigh River at Easton, PA
4. Del. River at Trenton, N. J.
5. Del. River at Bristol, PA
6. Del. River at Torresdale, Phila. PA
7. Del. River at Ben Franklin Bridge
8. Schuylkill River at Philadelphia, PA
9. Del. River at Chester, PA
10. Del. River at Del. Memorial Bridge
11. Del. River at Reedy Island Jetty, Delaware
12. Del. River at Ship John Shoal Lighthouse



In addition to the degradation and failure of sensors, the amplifiers and other electronics associated with the sensors are failure prone. Some of these failures are caused by handling and lightning strikes, of course. The submersible pumps are relatively trouble free, lasting six months to a year.

With periodic maintenance performed at one to three week intervals, about half the stations produce data at any one time. This low level of operational efficiency is unfortunate, but is tolerable for the time being since it provides data not otherwise available.

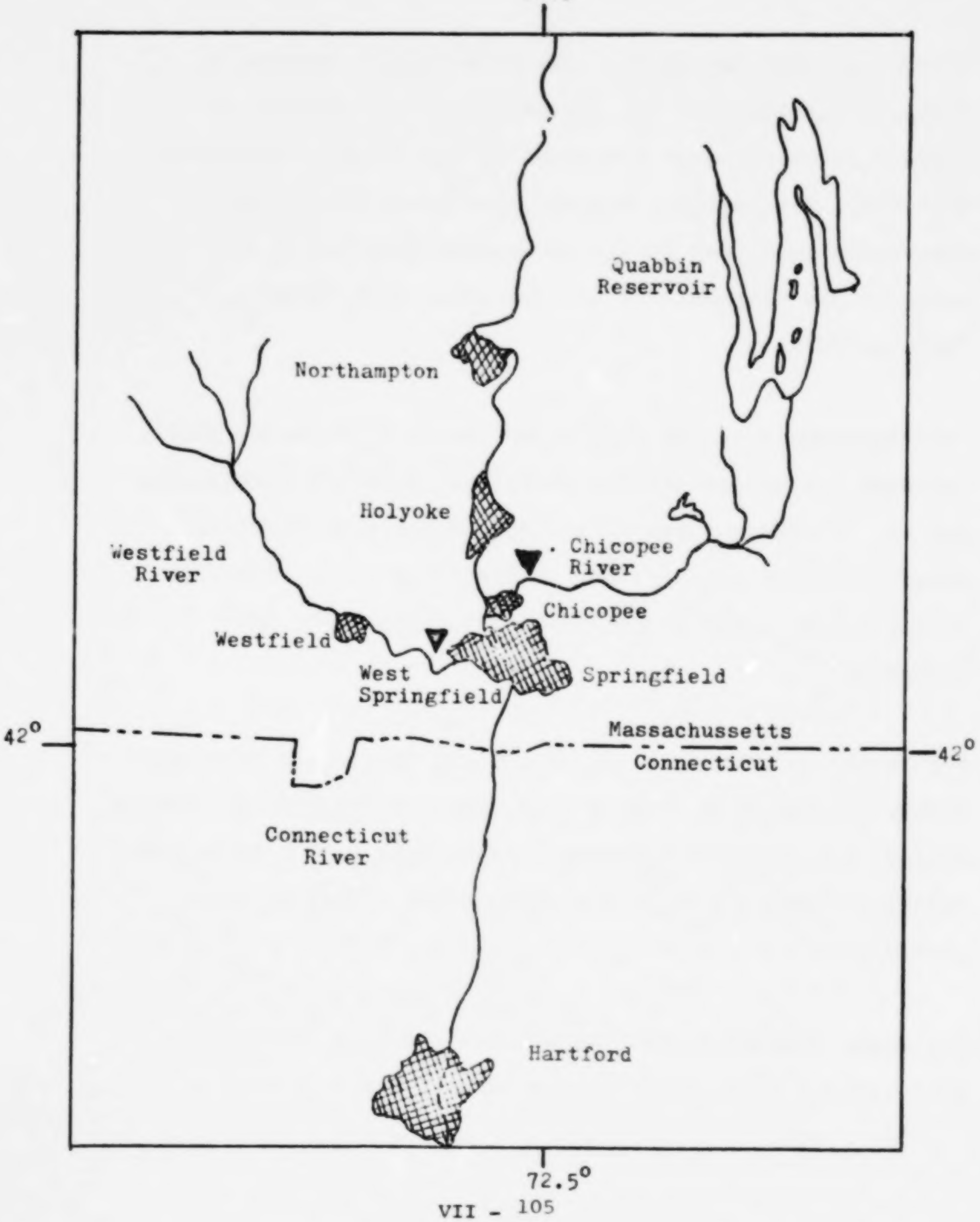
CORPS OF ENGINEERS NEW ENGLAND EXPERIMENT

The Army Corps of Engineers, New England Division deployed three water quality DCS installations on the North Nashua River at Fitchburg, Mass., the Chicopee River at Chicopee, Mass., and the Westfield River at West Springfield, Mass., (Fig. 4). These installations employ basically the same systems as the USGS Delaware Basin sites.

The Chicopee and Westfield sites have performed reliably, though no definitive check on data quality was available at this writing. These sites have operated for several months with maintenance performed every two to three weeks. The apparent success of these two sites is attributed to the relative cleanliness of the stream sites involved. Unfortunately, these sites are strictly experimental.

The third site at Fitchburg, Mass. (not illustrated) was intended to provide baseline data prior to proposed construction of low flow augmentation (pollution dilution) reservoirs. Parkinson's law holds and viscuous material from upstream paper mills keep clogging pump screens and burning out pumps. The site will be abandoned.

Fig. 4 CORPS OF ENGINEERS EXPERIMENT



NASA- WALLOPS STATION EXPERIMENT

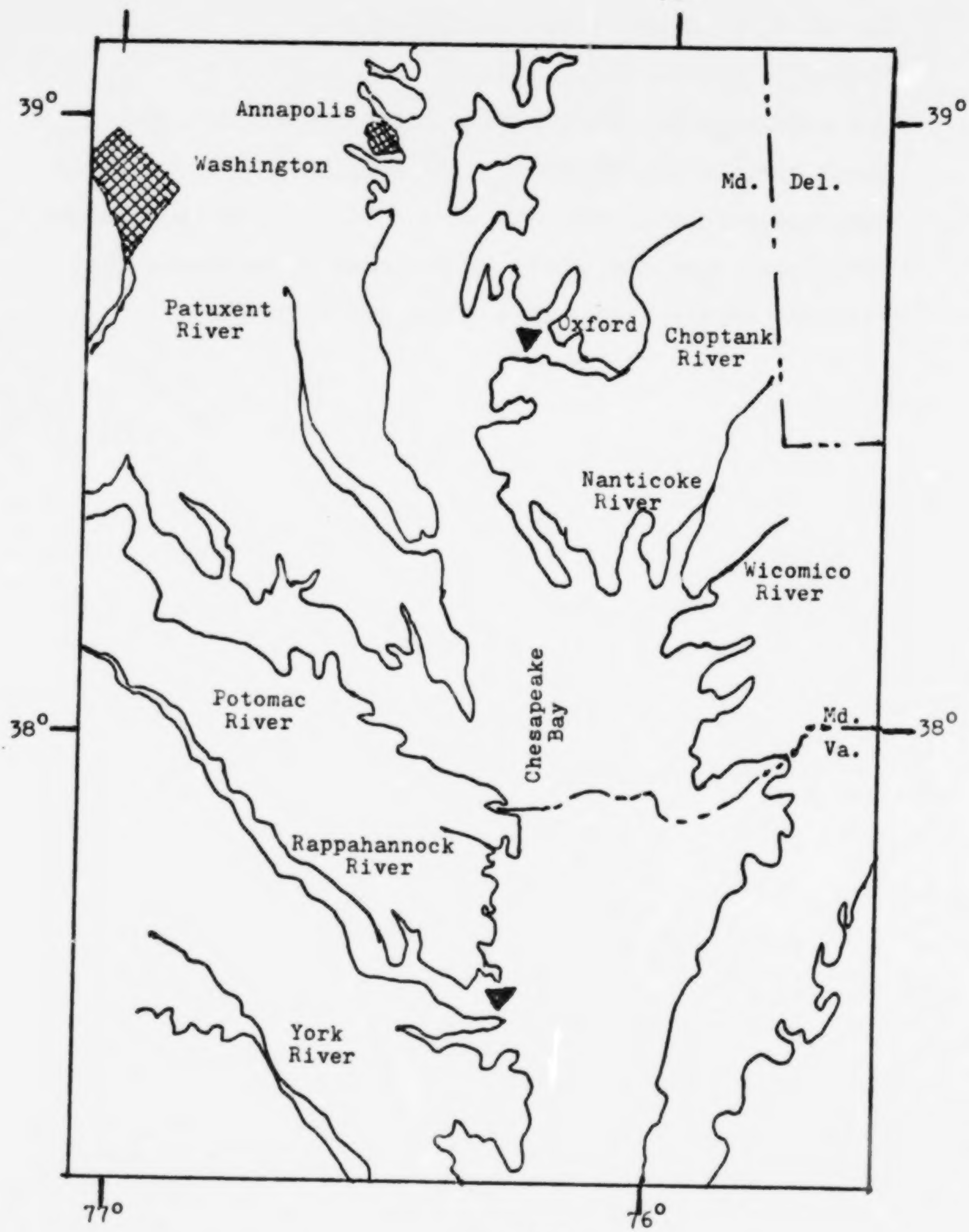
Within the last few months, the NASA-Wallops Station in Virginia has deployed two DCS water quality systems in support of experiments conducted by the Corps of Engineers, Vicksburg, Mississippi, office. The sites chosen are near-shore locations in the Chesapeake Bay; one at the mouth of the Rappahannock and the other near Oxford, Maryland (Fig. 5).

Instrumentation of the NASA sites consists of submersible instrument clusters mounted on pilings with the electronics and DCS antenna mounted at the top of the piling out of range of normal wave action. Sensors are included for conductivity, temperature, dissolved oxygen, pH, and turbidity.

The turbidity sensor, which is a light source and photocell device, degrades at a rapid rate with the adhesion of foreign matter on instrument surfaces in the light path. Data from this instrument is of little value after a week or so of service.

The other sensors accumulate surface coatings but produce good quality data after 18 days of use when tested in a

Fig. 5 NASA - Wallops Experiments



calibration tank prior to cleaning. A thick algae coating on the D. O. membrane had little effect.

The Rappahannock site was primarily affected by algae accumulation; the Oxford site by silt deposits. In these environments, the turbidity sensor was clearly inadequate. Additional experimentation is required to determine the required service interval for the other sensors.

CONCLUSIONS

The deployment of large, automated networks to acquire environmental data from surface monitoring stations requires field equipment capable of many weeks of reliable unattended operation. The ERTS-I Data Collection System experiment illustrates a pronounced failure of pollution sensing systems to meet this requirement. Indeed, they are the weakest element in the experiments.

Clearly, a concerted, national effort is required to develop pollution sensors and to approach installation and network designs from an overall system point of view.

ACKNOWLEDGEMENTS

The author, who is not an expert in pollution monitoring and water systems regulation, gratefully achknowledges contributions from the following people who are:

Mr. Saul Cooper and Mr. Joe Horowitz
U. S. Army Corps of Engineers, New England Division

Mr. Richard Paulson and Mr. Charles Merck
U. S. Geological Survey, Water Resources Division,
Pennsylvania District.

Mr. Duane Preble
U. S. Geological Survey, Gulf Coast Hydroscience Cente

Mr. Roger Smith
National Aeronautics and Space Administration
Wallops Station

SESSION VIII

ENVIRONMENTAL MONITORING APPLICATIONS

CHAIRMAN

MR. ROBERT F. HOLMES

OFFICE OF MONITORING SYSTEMS, OR&D

AIRCRAFT and SATELLITE MONITORING
# of LAKE SUPERIOR POLLUTION SOURCES

By

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Associate Professor,
Civil and Environmental Engineering Department
University of Wisconsin, Madison

and

John F. Van Domelen
Research Assistant,
Institute for Environmental Studies, and Ph.D. Candidate
University of Wisconsin, Madison

A paper presented at the U.S. Environmental Protection Agency's Second Environmental Quality Sensor's Conference.

October 10-11, 1973
Las Vegas, Nevada

BIOGRAPHICAL SKETCHES

JAMES P. SCHERZ, born 1937, obtained B.S. and M.S. degrees in Civil Engineering from the University of Wisconsin in 1959 and 1961. He has worked with the Highway Commission and on the state airborne magnetic survey of Wisconsin, and 4 years with the U.S. Army Corps of Engineers as a Regular Army Officer. He left the service in 1967 and began research at the University of Wisconsin on photographing water pollution and obtained his PhD in 1967. Since then, he has taught in the photogrammetry and remote sensing area and has been active in research work and consulting on remote sensing of water quality.

JOHN F. VAN DOMELEN, born 1942, obtained a B.S. in Applied Physics from Michigan Technological University in 1964, served 5 years as a Photo and Radar Intelligence Officer in the Regular USAF followed by a year as manager with a paper products company. He obtained an M.S. in Water Resources Management from the University of Wisconsin in 1972 and is presently engaged in a PhD program, in Civil and Environmental Engineering which he expects to complete in May, 1974. His major focus is in remote sensing determination of water pollution parameters.

ABSTRACT

Aerial and Satellite Photography can be a very valuable tool for water quality investigations. Such aerial imagery correlates with the water quality parameter of turbidity, which in turn under specific circumstances, correlates to other water quality parameters such as suspended solids or apparent color. The advantage of aerial imagery is that it provides an overall view of turbidity possible by no other means. One striking example of this potential use is in Lake Superior where an $8,000,000 water intake was located in turbid, unpotable water. The turbidity and its location was clearly visible on aerial and ERTS imagery. Another example of its potential use is where apparent reflectance of various lakes in northern Minnesota as obtained from ERTS imagery correlates very well with the turbidity, solids, and the U.S. Forest Service classification of eutrophication for these lakes. For correct analysis of aerial imagery for water quality, one must understand light penetration into

water and the corresponding bottom effects, as well as sky light reflection from the water surface. If these effects are understood and accounted for in a workable and practical manner, aerial and satellite imagery can indeed be a valuable tool for water quality investigations and should be used as such.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the following: Professor James L. Clapp and the staff of the Institute for Environmental Studies, Environmental Monitoring and Data Acquisition Group (EMDAG) for their administrative assistance; Kenneth Piech of Cal Span Corporation for his help in the planning of early work designed to determine the truth about depth penetration and bottom effects; the city of Cloquet, Minnesota which provided the financing for much of the field data acquisition relating to Lake Superior; to Dr. Kenneth Holtje and the U.S. Forest Service for their support in gathering field data near Ely, Minnesota; to Steven Klooster for the contributions he made towards the development of a practical means of analyzing remote sensing imagery of paper mill pollution, and to William L. Johnson for his help in the gathering and analyzing of data obtained from the lakes near Ely, Minnesota and his help in conducting settling tests on water obtained near Duluth, Minnesota. We also wish to acknowledge support received under the National Aeronautics and Space Administration Grant No. NGL 50-002-127 for Multidisciplinary Research in Remote Sensing as Applied to Water Quality.

INTRODUCTION

Remote Sensing is a valuable tool which should be used by anyone working with water quality.

A striking example is in Lake Superior near Duluth, Minnesota and Superior, Wisconsin, where an $8,000,000 water intake, without filtration facilities, was located in water that was turbid and unpotable over 53% of the time. Numerous aerial photographs on file in Superior, Wisconsin showed vividly this turbid water and its extent. These aerial photos were never used in the location process and the intake was constructed in the turbid water. In addition to aerial photography, ERTS imagery also shows this turbid water, its extent, and its movements. (13)

Not only is turbid water shown quantitatively on these aerial images but a court-related investigation into the matter revealed that the water quality parameter of turbidity correlates with the imagery at all times. Other water quality parameters such as suspended solids sometimes can also correlate with turbidity. To the extent that they do, they can also be mapped by aerial photography. Similar results have been arrived at by looking at industrial pollution sources and at the clearness of some lakes in various stages of enrichment. (5)

In addition to the data gathered at Lake Superior relating to this court case, this paper also presents data pertaining to industrial pollution and lake eutrophication. These examples are included so as to more clearly show how remote sensing can be effectively used as a quality monitoring tool for various waters.

In all cases, "noise" effects, are present and must be properly dealt with. These include: Surface reflection from the water surface, and bottom effects (14). Scatter in the atmosphere, and effects from the camera lenses and film development also contribute, but to a less significant degree. This paper considers these effects and suggests how they can be understood and dealt with so that remote sensing can be a valuable tool in water quality investigations.

BASIC RELATIONSHIP

Aerial photos have long been effectively used by professional people in areas such as forestry, agriculture, and soils. On the other hand aerial photographs have not been effectively used by most practicing sanitary engineers whether they are working with water pollution or locating drinking water intakes. Perhaps one reason why photography has not been effectively used by people actively engaged in the water quality and supply field is because the interaction of the sun's energy, with a water body, is a complex process and this process, in the past, has not been widely, nor fully understood. However, it is now felt that these interactions are sufficiently understood, so that aerial photographs can and should be used for water quality investigations.

The sun's rays interact first with the water surface. A portion of the light from the sun and the sky (including clouds) are reflected from this water interface (see Fig. 1). This reflected energy is called surface reflection. A portion of the light enters the water, interacts with the material in the water and is scattered upward to the camera. This is herein called volume reflectance. The volume reflectance is the critical item, as it indicates the quality of the water. In shallow, clear water, a portion of the light may pass through the water and reach the bottom where it can be reflected back through the water body and up to the camera. Those rays which strike the bottom, pass back up through the water body, create bottom effects and are undesirable noise in the system; unless one desires to map bottom vegetation.

Because surface reflection, volume reflectance, and depth penetration and bottom effects are all wavelength (color) dependent, the whole question becomes even more complex. For example, the short wavelengths like (ultraviolet and blue) are reflected primarily from the surface of the water, while the longer ones are not. Infrared energy penetrates least into the water while green energy penetrates the most; the light returning as volume reflectance is entirely dependent upon the type of material in the water. (12, 8)

The light reaching the camera is therefore, the sum of the surface, volume, and bottom effect phenomenon. Normally one is only interested in the volume effects and the other effects must be separated out. However, the magnitude of surface reflection can be altered by oil spills and this then becomes the desirable factor to monitor. In all other cases, the surface reflections are undesirable. Since sky-light is always reflected from the water surface, and since the reflection from a cloud is much brighter than from the blue sky, for water quality investigations one should use aerial photography taken only on a clear day or on a uniformly overcast day in order to avoid local hot spots of high surface reflection caused by scattered clouds. The sun's reflection can be eliminated by simply picking an angle where sun glitter does not show.

The depth penetration and bottom effects can present a problem depending on the turbidity of the water. Since a secchi disc really is a field means of determining turbidity, it can effectively be used to ascertain if the bottom effects are significant. (15) The white secchi disc is lowered into the water until it disappears from sight. The depth at which this occurs is called the secchi disc reading. The aerial camera will essentially see no further into the water than the secchi disc reading. (14) As a general rule,

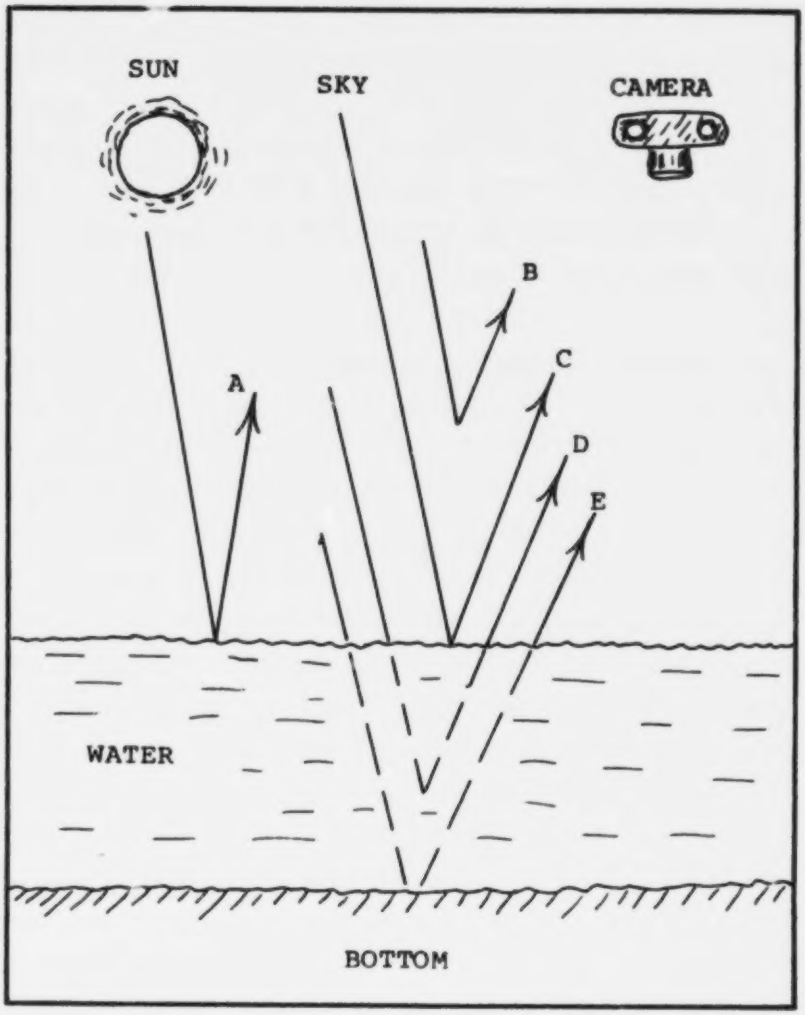


Fig. 1. Components of light that the camera captures caused by various interactions of light on, in, and through the water.

A = Surface Reflection of the Sun
B = Atmospheric Scatter
C = Surface Reflection of the Sky
D = Volume Reflectance of the Water
E = Bottom Effects

if the reading is less than the depth to bottom, one can assume that no significant amount of energy returns from the bottom to effect the aerial image. Where bottom effects are present, it is still possible to analyze aerial photographs of the water if the infrared wavelengths are used because infrared energy penetrates only a few inches into the water.

The central question therefore, is how are volume reflectance effects associated with water quality parameters, and how can aerial photographs be used to obtain these parameters in a reliable manner?

EQUIPMENT

A. Aerial Cameras

The remote sensing program at the University of Wisconsin makes use of 9 X 9 inch mapping cameras where high metric accuracy is of utmost importance. However, experience has shown that in most water quality investigations, the location of a pollution plume to within a fraction of a foot is of little importance. It is the spectral response of the water that is crucial. For such work, 35 mm cameras are used, because of their economy and the simplicity of their data storage and retrieval characteristics. (7) The data gathered for this research was done with a two camera bank using 35 mm single-lens reflex cameras - normal color film used in one camera and color infrared red film was used in the other. The normal color film has three layers sensitive to blue, green and red energy. The color-infrared film has three layers sensitive to green, red and infrared energy. Each layer, of each exposed film, can be analyzed to ascertain the reaction between the different energies and the objects during exposure. These films are analyzed on a microdensitometer which is attached to a spectrophotometer. This will be referred to as a color microdensitometer. (4)

B. Microdensitometer

Figure 2 shows the color microdensitometer apparatus used to analyze the film. With this apparatus it is possible to analyze the energy at wavelengths or colors of the film. In other words, it is possible to measure the color transmittance of the film at any point on the photo. (4)

C. Spectrophotometer

If the microscope part of the microdensitometer is replaced by a larger telescopic head as in Figure 3, we have a spectrophotometer which can analyze

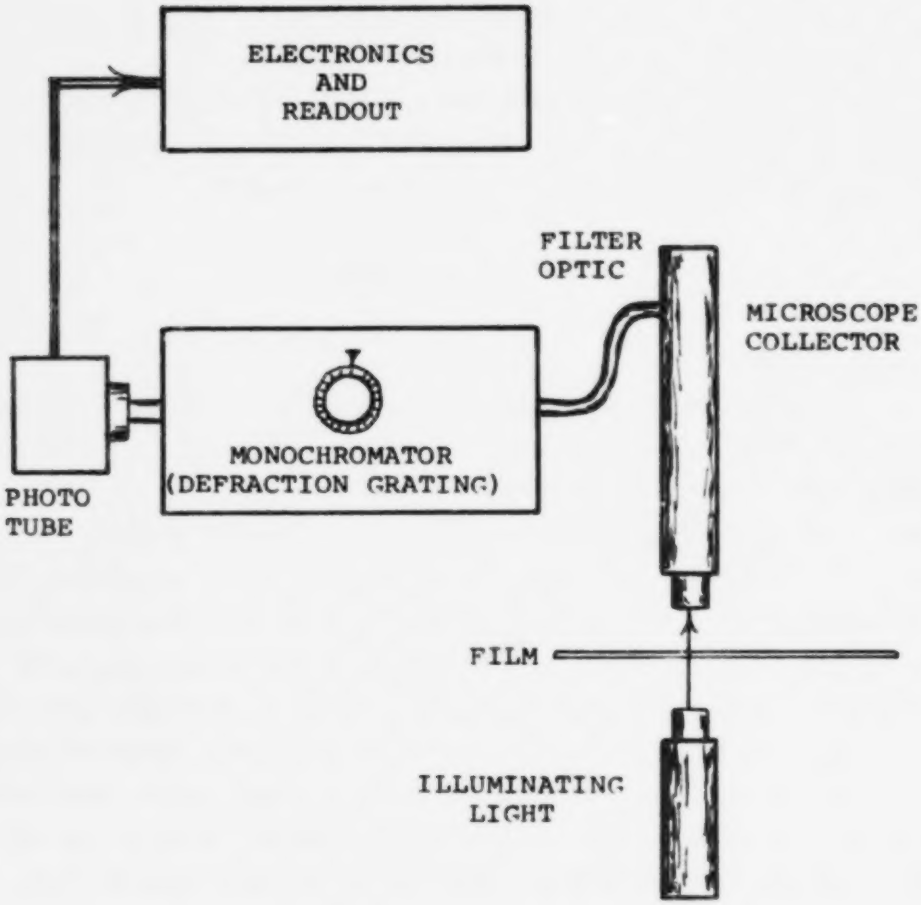


Fig. 2. Block diagram of color microdensitometer for analyzing film. The illuminating light directs light through the film into the microscope collector. Then a fiber optic directs the light through a defraction grating into a photo tube. In this manner the intensity of any color can be analyzed for any point on the film.

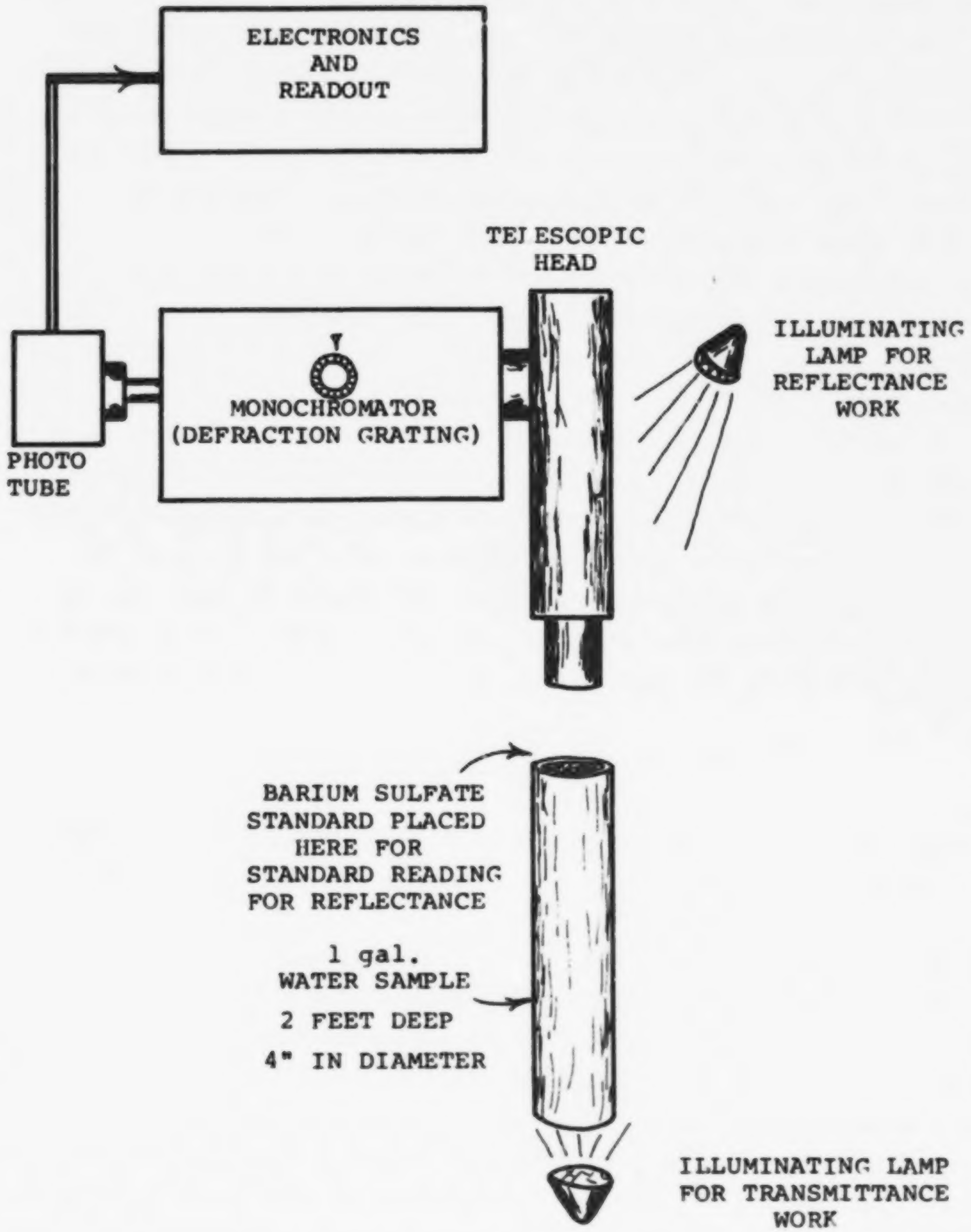


Fig. 3. Spectrophotometer block diagram for analyzing water samples.

the transmittance or reflectance of a water sample. Light is placed under the sample tube so the rays penetrate through the tube, enabling one to compare incidental energy to transmitted energy. When the light is placed such that it shines down on the surface of the sample, energy is scattered back, and one can measure the reflectance of the water. This reflectance is important because it is essentially the volume reflectance that is desired in the water analysis work already mentioned. To get the absolute value for reflectance from a water sample, a reading is first taken on a barium-sulfate standard of known reflectance, and the water reading is compared to it. The ratio of the water reading to the reading of the barium-sulfate is herein termed the volume reflectance of the water. Assumptions are that there is no reflection of bright ceilings from the water surface and that the reflection from the bottom of the sample tube is negligible.

In the field, a styrafoam panel of known reflectance is placed in the water and photographed. When the microdensitometer is used to analyze the film, readings are taken from the image of the panel and then from the image of the water. The ratio of the readings from the water and the panel are herein called apparent reflectance. Apparent reflectance includes sky-light reflection and is always larger than the laboratory derived volume reflectance. For correct analysis of the photo, there must be no bottom effects present.

LAB WORK TO FIELD WORK CORRELATION

For aerial photography to be effectively used in water quality investigations, there is a certain necessary balance between laboratory and field work.

A. Water Quality Using Aerial Photos

Anyone observing a photograph of an industrial plant spewing waste into a stream intuitively realizes that there is a relationship between the relative brightness of the waste on the photograph and the concentration of that pollution. He might ask, "What water pollution parameters correlate with the photo and how is this correlation possible?" Figure 4 shows a waste discharging from a paper mill in Wisconsin. In the summer of 1972 hundreds of water samples were taken within the plume. At the same time, an aircraft flew overhead taking color and color infrared photographs. Standard reflection panels were strategically placed throughout the plume. On the resulting photos, color

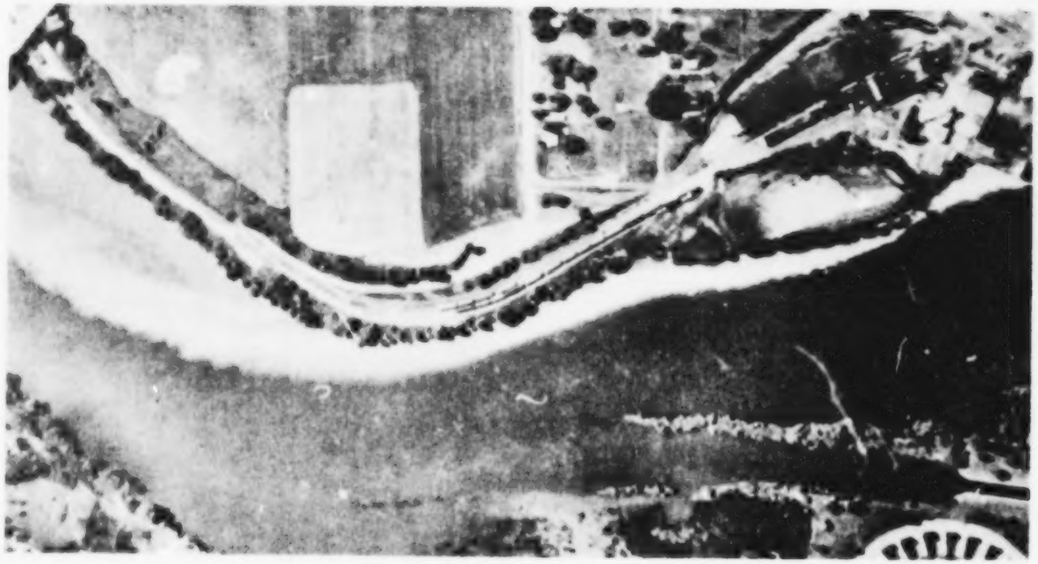


Fig. 4. Photograph of a waste discharging from a paper mill.

microdensitometer readings were taken of the standard reflection panels and other readings were taken of water at the sampling points. Ratioing the two yielded the apparent reflectance which included the sky-light reflection. This process was repeated for many wavelengths and Figure 5 shows the resultant apparent reflectant curves.

Figure 6 is a plot of apparent reflectance, at 0.55 microns, versus turbidity and solids for various points within the plume shown in Figure 4. The apparent reflectance was obtained from the photographs. Figure 6, also illustrates the relationship between the reflectance, as obtained in the laboratory, and values obtained for turbidity and solids. The higher values obtained from the field occurred because the photographs also contain sky-light reflection, while the lab samples do not. Figure 6 emphasizes the fact that there is indeed a straight line relationship between apparent reflectance, turbidity and solids. For low concentrations of wastes, the bottom of the lab sample tube begins to interfere which causes lab results for these lower concentrations to be in error.

From the above, it appears that one needs to obtain only a few water samples at the instant of an aerial overflight to make positive correlation between the water and the photograph. A suggested method would be to take a sample in the dirtiest part of the plume, a sample of the receiving water and a sample in the middle of the plume. The apparent reflectance from these samples can then be used to ascertain a field curve for mapping water quality parameters. If desired, the dirty water can be diluted with the receiving water to obtain a lab curve, similar to that of Figure 6. The difference between the two is a measure of sky-light reflection and other variables. there must be no bottom effects present in the field. If there are, then any analysis must be made only in the longer infrared wavelengths such as 0.75 microns.

Unless the camera and film conditions, altitude and lighting conditions, and cloud and atmospheric conditions are identical on both days, it is not possible to use reflectance-turbidity curves from one day to analyze the water conditions on a second day. Figure 7 shows three reflectance-turbidity curves from the paper mill in Figure 4.

The curve for 8/19/71 was obtained from photography taken at 1800 feet on a uniformly overcast day. One will note that high values of apparent reflectance are obtained due primarily to the high reflection of the clouds from the water surface. The curve from 8/11/71 was also obtained from photography

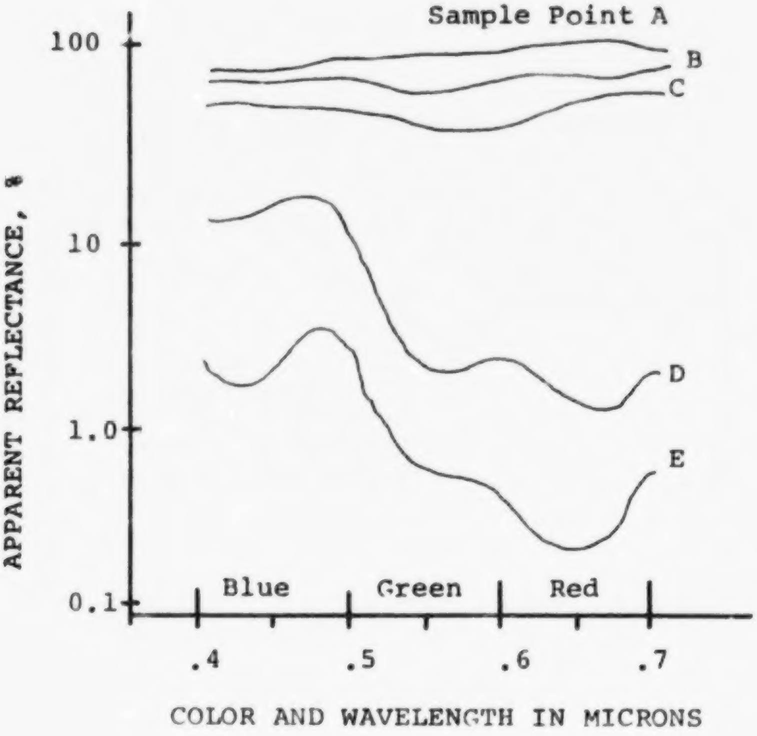


Fig. 5. Apparent Reflectance of water at various points in the pollution plume shown in Fig. 4. These values are obtained by analyzing color film with the color microdensitometer and comparing the reading on the water with that of a standard styrafoam panel. The values of turbidity and suspended solids associated with the water sample points are as follows:

Water Sample Point	Turbidity JTU	Suspended Solids mg/L
A	110	172
B	75	100
C	40	50
D	18	23
E	11	8

One will note that there is indeed a good correlation between apparent reflectance and the values of turbidity and suspended solids.

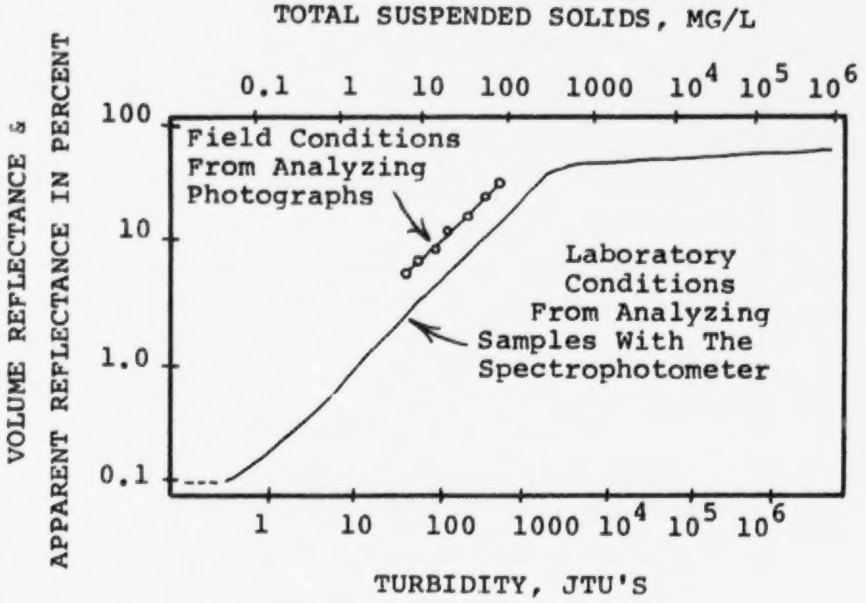


Fig. 6. Volume reflectance for laboratory samples and apparent reflectance for field conditions plotted against turbidity and total suspended solids. The wavelength used was 0.55 Micron (color green). The fact that the apparent reflectance from field conditions is higher than the lab conditions is primarily due to sky-light reflection. The aerial photos show sky-light reflection, while the lab analysis does not.

shot at 1800 ft., but the values are lower because the cloud cover was much thinner and the surface reflection of the clouds was less. The reflectance - turbidity curve for the photography taken at 2800 ft. is drastically different than the one for 1800 ft. It is clear that changes in altitude, especially on a hazy day are extremely important.

Therefore with imagery obtained by aircraft where the altitude, time, and cloud conditions vary, if one wishes to obtain absolute values of turbidity and suspended solids from the photo, a few simultaneous water samples must be taken somewhere in the strip of photos to establish the reflectance - turbidity curve for that particular set of circumstances.

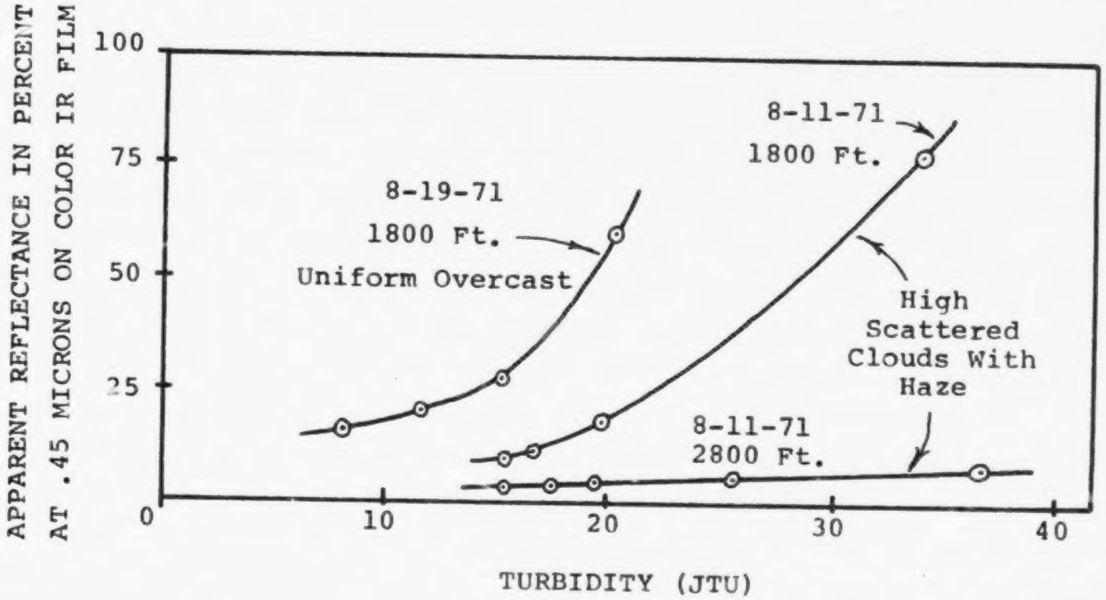


Fig. 7. Change in Reflectance-Turbidity Curve due to changes in cloud conditions and altitude.

B. Water Quality From Satellites

The most important correlation to be made, is between the water itself and the aerial photo. Once this is done, the correlation between aerial photos and satellite imagery is not that much more difficult. The most significant difference is the amount of atmosphere between the plane taking the aerial photo and the several hundred mile height of the satellite.

There are really less variables when working with ERTS satellite imagery than with aerial photos. Usable satellite imagery exists only for absolutely clear days, so the sky-light reflection on a satellite photo is a minimum, and is always the same. The altitude of the satellite is essentially always the same. The angle of the sun and the time of photography are also approximately constant. Also the ERTS imagery is internally uniformly calibrated so there is no significant changes due to camera and film factors. With ERTS satellite imagery there is very likely only one reflectance - turbidity curve that must be established for a particular water. Once established the ERTS imagery can be analyzed in conjunction with this curve to ascertain water quality for any day.

Figure 8 is an ERTS image of the western end of Lake Superior, near Duluth, taken on 12 August 1972. There is obviously some dirty water in the bay near the cities of Duluth and Superior. An $8,000,000 water intake for the city of Cloquet, Minnesota was located in the middle of the turbid water. A lawsuit against the engineer resulted. The ERTS imagery showed the extent of this turbid water in a manner better than could be ascertained by any other means. There was therefore much interest in establishing the relationship between the water conditions and the brightness of the ERTS image.

In conjunction with the law suit, water samples were taken near Duluth immediately after a storm in November 1972. Simultaneous water samples and aerial flights were accomplished. The suspended solids of the water samples ranged between 40 to 400 mg/l. Turbidity ranged between 10 and 100 JTU's. Secchi disc readings varied from 9 feet in the clear water to 8 inches in the turbid water. The depth of the bay was about 40 feet, so bottom effects were not significant in this case.

Figure 9 shows the lab-derived volume reflectance versus turbidity curve for synthesized muddy water and the apparent reflectance versus turbidity curve obtained from analyzing the photographs. The difference between the two is attributed to the surface reflection of sky-light and other noise effects. There

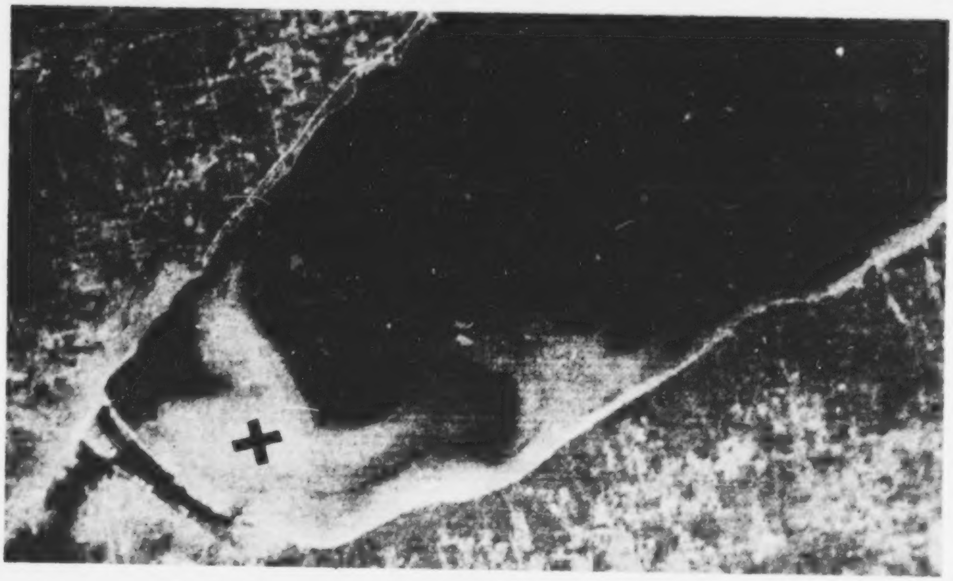


Fig. 8. ERTS Satellite Image taken 12 August 1972 showing the south west end of Lake Superior near Duluth. Note the dirty water. An X marks the spot where an $8,000,000 water intake was located which when put into operation produced turbid unusable water.

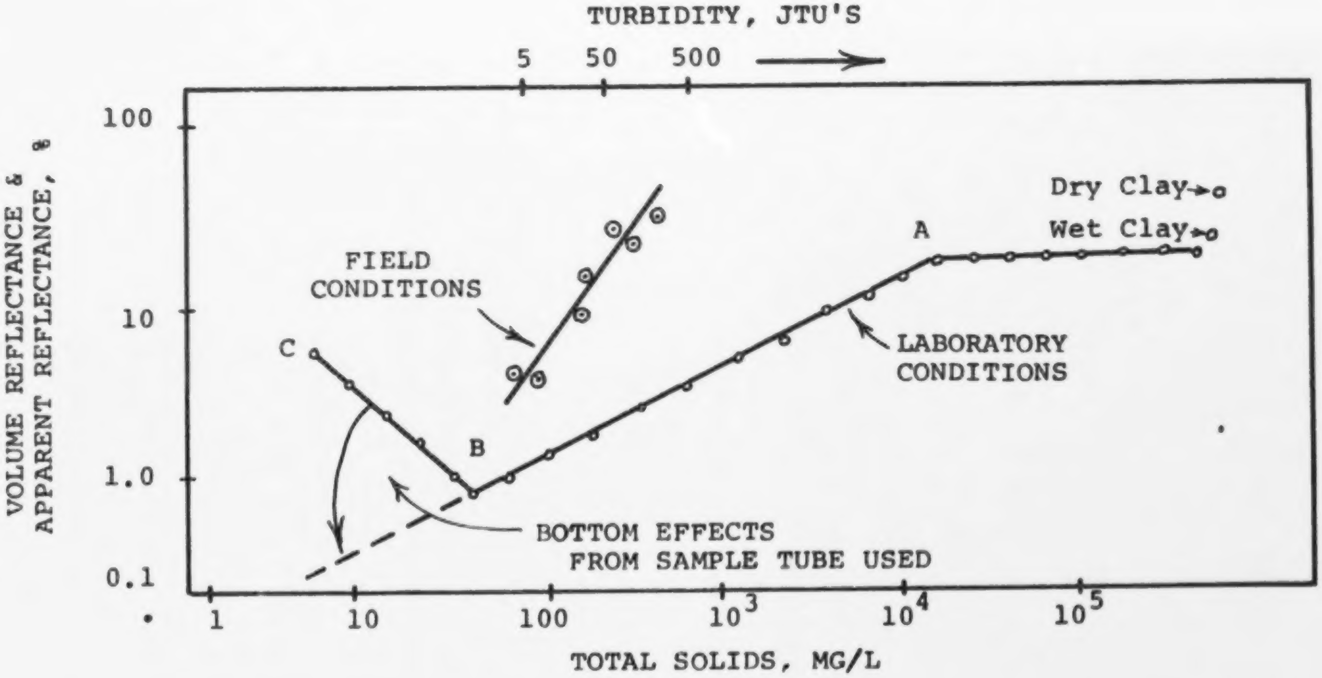


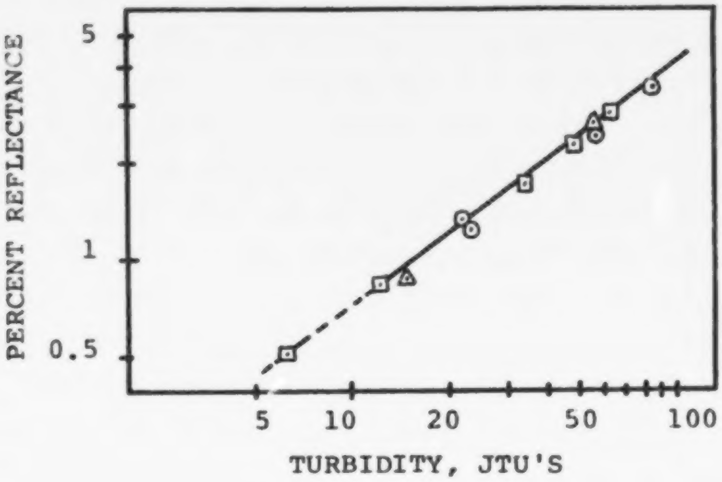
Fig. 9. Laboratory volume reflectance and also apparent reflectance from color and color infrared photographs plotted against turbidity and total solids. The wavelength used was 0.65 Microns (color red). The location is Lake Superior near Duluth. The material in the water is red clay which shows up on aerial photos and ERTS images. On the laboratory analysis between points B and C the effects of a shiny bottom of the sample tube are overriding, making this data erroneous. These effects have subseqently been reduced by using a flat black bottom for the tube. The vertical displacement between the curve for field conditions and lab conditions is primarily due to the fact that sky-light reflection is present on the photos, but not present in the lab analysis.

is a good correlation between turbidity and apparent reflection. Similar field tests were run two and three weeks after the storm. The dirty water remained in the bay during this time but its characteristics changed, due to settling of the heavier particles. When all the laboratory data from the 3 days were combined the plot between lab-derived volume reflectance versus turbidity and secchi disc readings hold well for all three days (see Figure 10).

It was obvious that it was the parameter of turbidity that correlated at all times with the reflectance and therefore the brightness of the ERTS imagery. An analysis was then made to see what other parameter correlated to turbidity. As the secchi disc reading is just a rough field means of measuring turbidity, it provided a good correlation to turbidity, which is also shown in Figure 10. Suspended solids were the only other parameter that came close to correlating with turbidity. Even then there was a distinctly different suspended solids - turbidity curve for each of the three days (see Figure 11). On any one day there was a very good correlation between suspended solids and turbidity. Therefore, for a given day, if one had the proper ground truth, suspended solids as well as turbidity, could be mapped from the ERTS imagery. The reflectance - turbidity curve holds for all days so on any day for the dirty water near Duluth, one can obtain the reflectance from analyzing the ERTS image, and from it can calculate the turbidity. Also from the reflectance and the reflectance - secchi disc reading curve in Figure 10, one can obtain the secchi disc reading for water anywhere in the ERTS image. The aerial image sees no deeper than the secchi disc reading. (14) Therefore by comparing the calculated secchi disc readings with a hydrographic chart of the area it is possible to tell if bottom effects are significant on the ERTS imagery.

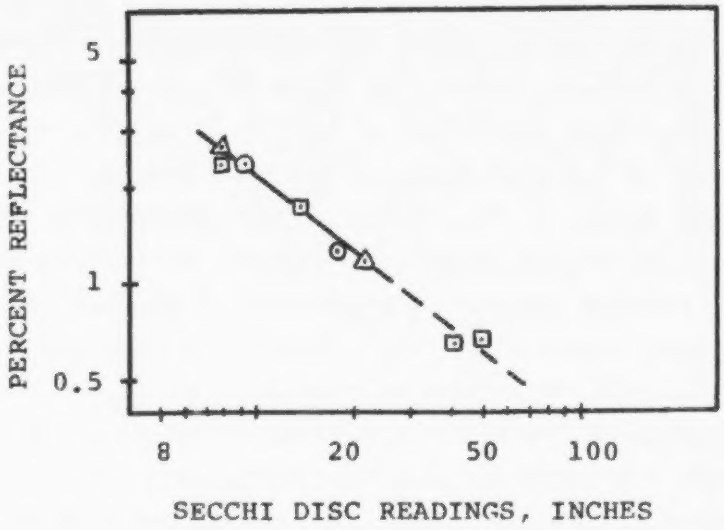
The ERTS image, Figure 8, was analyzed with a microdensitometer, to obtain values of apparent reflectance at various points in the lake. These apparent reflectance values on Figure 9 resulted in turbidity values for the points ranging from 4 to above 100 with the calculated turbidity at the intake location being about 80. An exact check of the satellite's reliability and the effect of the intervening atmosphere would have required water sampling simultaneous with the ERTS overflight. This of course, was not accomplished in August 1972, but can be done in future tests.

Another potential use of satellite imagery presented itself in an investigation conducted with the U.S. Forest Service. They were interested in the potential use of satellites for categorizing the clarity of lakes near



Reflectance vs. Turbidity

⊙ = Water Samples Collected 4 November 1972
(2 days after a heavy storm)
△ = Water Samples Collected 17 November 1972
⊡ = Water Samples Collected 23 November 1972



Reflectance vs. Secchi Disc Readings

Fig. 10. Laboratory Reflectance versus Turbidity and Secchi Disc Readings for all of the water samples collected during the 3 days in November, 1972. The location is dirty water in Lake Superior near Duluth as shown in Figure 8.

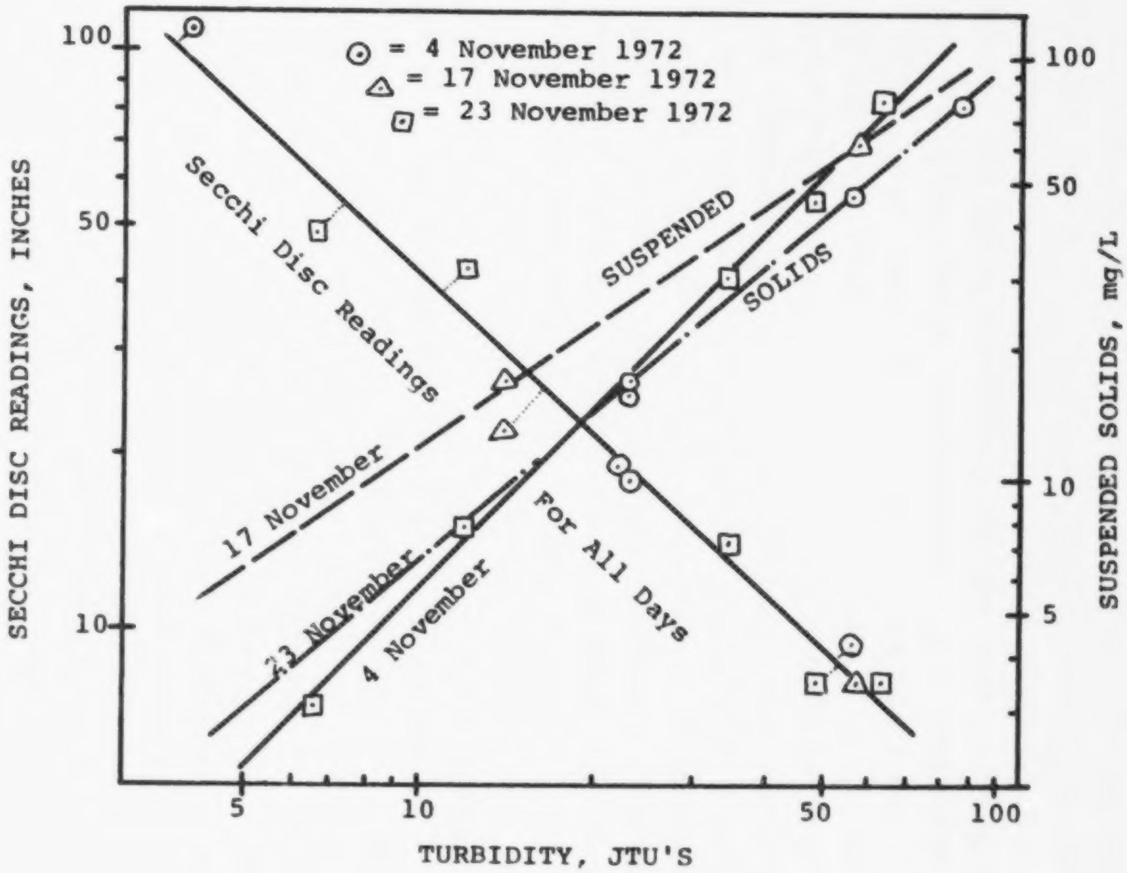


Fig. 11. Plot of Secchi Disc Readings and Suspended Solids versus Turbidity for all of the water samples collected in dirty water in Lake Superior near Duluth in November 1972.

Ely, Minnesota, which is located in the northwest corner of the full frame just off the illustration in Figure 8. Three lakes were sampled and the samples analyzed during the summer of 1973: (1) Lake Shagawa classified as eutrophic (enriched) (2) Lake Ensign, somewhat more clear and classified as mesotrophic and (3) Lake Snowbank, a very clear lake classified as an oligotrophic lake. Reflectance values were obtained from the water samples from these lakes and an analysis was made for solids and turbidity. These values are presented graphically in Figure 12. It is apparent that there is a very good correlation between volume reflectance and turbidity and solids as well as the lake classification used by the Forest Service. When the ERTS image was analyzed with the microdensitometer, the apparent reflectance data yielded a straight line, about 5% higher than the laboratory data. This case provides a direct comparison of lab results with satellite data and the results are essentially the same as that shown on Figure 9 (a comparison between the lab data and low flying aerial photography). In both cases, the field curve is about 5% higher than the lab curve with a somewhat steeper slope. It appears that the skylight reflection effects in both cases are essentially similar. Further work by John Van Domelen is focused on better ascertaining the exact magnitude of the skylight reflection for all situations.

C. Effects of Oil on Sky-Light Reflection

In Figures 6, 9 and 12 the vertical shifts between lab and photo (field) reflectance values are attributed to sky-light reflection. If the sky conditions are uniformly clear or overcast this effect will be essentially constant over the photograph. We also assume that the surface reflection of the water itself is uniform. This is generally the case, but if oil is on the water surface, it can significantly alter locally, the amount of reflection. Assuming all else remains constant, the amount of surface reflection varies almost linearly with the amount of thickness of the oil spill. Oil film detection is most pronounced on overcast days because the sky-light, which the oil reflects, is much brighter on such overcast days. So if all else remains constant, one can also monitor oil thickness changes by the apparent reflectance as shown on the photo. This area is presently being studied by John F. Van Domelen.

CONCLUSIONS

Many experts in water quality work are reluctant to use aerial photos in

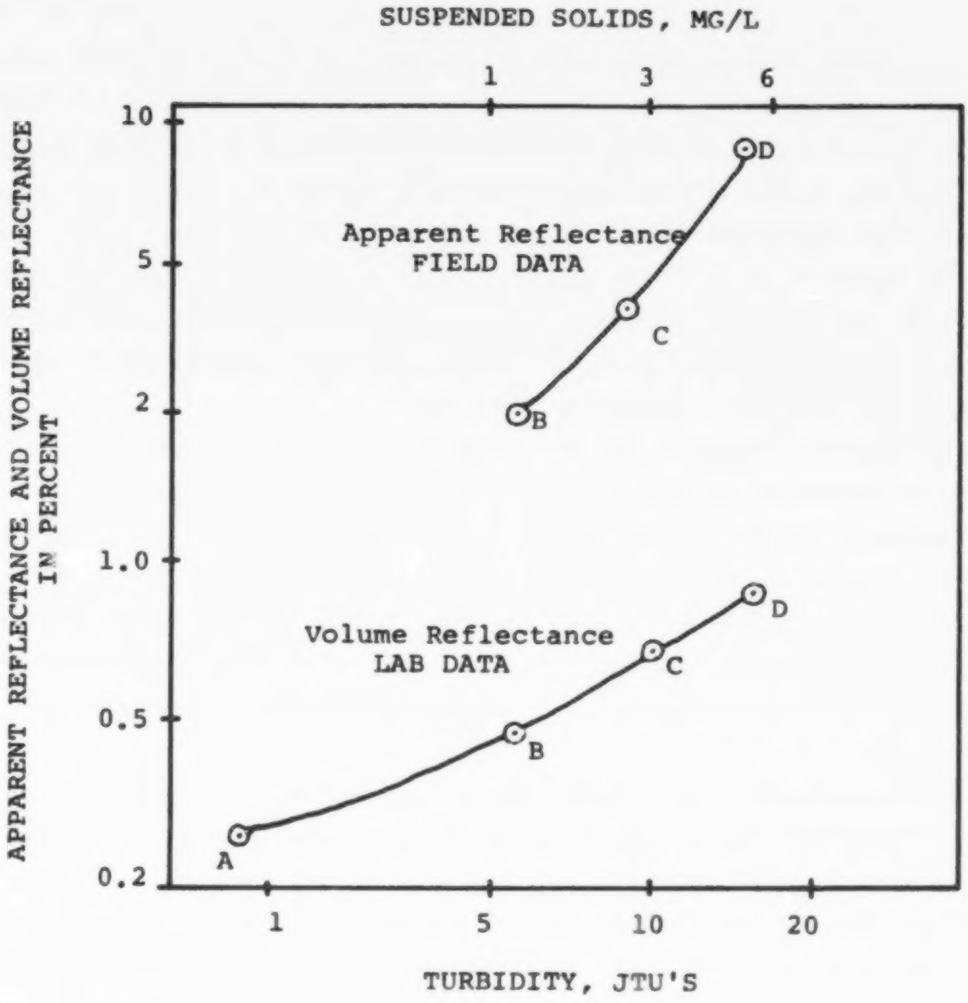


Fig. 12. Volume Reflectance from analyzing water samples in the lab and apparent reflectance from ERTS imagery plotted against turbidity and suspended solids. The three lakes analyzed are classified in three different stages of enrichment or Eutrophication as follows:

Sample	Lake	U.S. Forest Service Classification
A	Distilled Water	NA
B	Snowbank Lake	Oligotrophic (clear)
C	Ensign Lake	Mesotrophic(Middle Stage)
D	Shagawa Lake	Eutrophic (enriched)

their work. However, when properly used, photography is a very important and useful tool for water quality investigations. Anyone observing an aerial image of industrial pollution or of siltation extending into clear water intuitively realizes that these photos qualitatively show water conditions and the distribution of any disturbing material. Further refinement of image analysis and water analysis makes it possible to quantitatively obtain turbidity from aerial photos. To whatever extent suspended solids and other water quality parameters correlate with turbidity, these can also be quantitatively mapped, provided that simultaneous water sampling is properly conducted.

The interaction between light and water is quite complex and these interactions must be understood before aerial photos can be effectively used. Important considerations are the surface reflection of the sun and sky-light energy. Except for the monitoring of oil spills, surface reflections are considered an undesirable noise, but if aerial photos are taken either on completely clear or uniformly overcast days the sky-light reflection can be uniformly quantified and dealt with. The sun's reflection can be avoided by proper choice of the camera look angle.

Another undesirable noise factor can be bottom effects. However, if a secchi disc is used and the reading obtained is less than the depth to bottom, the bottom effects are not important. If the secchi disc reading is greater than the bottom depth, bottom effects are an important factor, and the analysis of aerial images must be done in the near infrared spectrum as infrared energy penetrates only a few inches into the water.

The desirable factor to be analyzed is volume reflectance, as the water quality parameter of turbidity correlates to volume reflectance. This general correlation can be determined either in the laboratory or in the field. From a photo, the apparent reflectance for the field conditions are higher than those from the lab because of sky-light reflection. To ascertain the slope of the turbidity versus apparent reflectance curve and its vertical shift due to skylight, water sampling must be done simultaneously with any overflight. This is in keeping with conventional photogrammetry practices. As ground control is to photogrammetry, so is ground truth sampling to remote sensing. Remote sensing will not eliminate ground water sampling, it just makes it thousands of times more efficient.

Enough is now understood about the interaction of light rays with water so that remote sensing can now be utilized as a tool for water quality investigations, and it should be so used. Had the designer of the water intake in Lake Superior near Duluth properly looked at aerial photos showing the areas of turbid and clear water, the intake should have been located 6 miles to the northwest and taxpayers in that area would have a functional water intake instead of an $8,000,000 blunder.

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LIDAR POLARIMETER MEASUREMENTS OF WATER POLLUTION

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ABSTRACT

Laboratory measurements of laser light backscattered by turbid water and oil on water have indicated a potential for dual polarization laser radar (Lidar Polarimeter) for remote water pollution monitoring. A lidar polarimeter system employing a 5 mw He-Ne laser has been constructed and used in laboratory and daylight field measurements of turbid water and thin oil spills. The system concept is based on an electromagnetic backscatter model which attributes depolarized backscatter to multiple scatter within the subsurface volume. This component is related to the number density and sizes of suspended particles within the volume. The experimental system described records both the like and cross polarization backscatter components for either horizontal or vertical transmit polarizations.

The laboratory system is being expanded for the Coast Guard to include two lasers operating at 633 nm and 441.6 nm to enable continuous monitoring of oil spills. The four backscatter components are to be processed in real time using a digital signal processor which classifies the status of the water according to turbidity or oil spill condition.

This paper describes the lidar polarimeter concept, system configuration, and field measurements conducted at Texas A&M University.

INTRODUCTION

In 1972 Rouse [1] published the results of a theoretical study of electromagnetic backscatter from rough surfaces which showed that the depolarized backscatter component was dependent upon a near-surface volumetric scattering process. This work was based upon previous theoretical studies by Fung [2] and Leader [3] and experimental studies by Renau et al [4], Cheo and Renau [5], and Leader [3]. As a result of these efforts, the interpretation of both optical and microwave backscatter measurements have been modified, since previous rough surface models had predicted depolarization due solely to multiple scatter on the surface.

In an effort to establish the validity of the model, a series of laboratory measurements are being made using a He-Ne laser source. This activity has led to the development of a new sensor instrument called a Lidar Polarimeter. This device has shown potential for remote measurements of turbid water and oil on water. The sensor is still in a developmental stage and field confirmation of certain effects seen in the laboratory is yet to be obtained. The purpose of this paper is to describe this lidar polarimeter and summarize the preliminary experimental results.

SENSOR CONCEPT

The scattering model developed by Rouse [1] is based upon the assumption that electromagnetic backscatter from inhomogeneous, rough surface dielectrics can be obtained by assuming a volume scatter component added incoherently with a surface scatter term. In the model, the volume scatter process is described by a linear transformation of the surface fields. The volumetric scattering process is controlled by the transmission properties of the surface and the inhomogeneity of the volume. In Rouse's work, the depolarized backscatter is also dependent upon the surface statistics.

In an independent study by Leader [6], a similar model was developed which has the same general properties, except that the depolarized component is independent of the surface roughness. A later study by Wilhelmi [7] expanded upon these two studies and led to a formulation based on the physical optics approach which shows excellent agreement with experimental measurements. Wilhelmi's model supports Leader's observation that the depolarized backscatter is independent of surface roughness and is strongly dependent upon the number density of particles within the subsurface volume.

The general nature of the like and cross polarized backscattered power received from a rough surface is:

P_{ii} = Surface Component + Subsurface Component

P_{ij} = Subsurface Component

Where i, j denote transmitted and received polarization.

At microwave frequencies, the subsurface components are generally much less than the surface components. This is true whether the target is land or water. However, at optical frequencies, the subsurface component can be significant, especially if the target is turbid water.

LIDAR POLARIMETER

The lidar polarimeter developed at Texas A&M University employs a low-power CW helium-neon (633nm) laser which transmits a narrow beam of polarized, chopped monochromatic light. A narrow beam, dual-polarization receiver detects both vertically and horizontally polarized light backscattered from the illuminated target. The field of view of the receiver is matched to that of the transmitter. A narrow-band optical filter, small angular field of view, and synchronous demodulation of the detected radiation are combined to eliminate signals produced by skylight and

and scattered sunlight. During operation the laser beam is directed away from the nadir at a sufficient angle to insure a predominance of diffuse backscatter. The basic system diagram is shown in Figure 1.

The present system is capable of operation at slant ranges of about 30m over natural waterways having depolarized scattering cross sections as low as -50db. The measurements can be made independent of lighting conditions and the effect of atmospheric interference is minimized. The operational configuration is shown in Figure 2.

MEASUREMENT OF TURBID WATER

Laboratory measurements of two types of turbid water solutions were made to determine the effect of the subsurface volume composition on the depolarization process. One solution consisted of water with suspended spherical particles of teflon (Dupont TFE 30) ranging in size from 0.04μm to 0.4μm diameter. The solution also contained varying concentrations of nigrosine black dye. The beam extinction coefficients due to scattering and absorption were found to be

$$\alpha_s = 85\rho_s \text{ cm}^{-1}$$

$$\alpha_a = 6600\rho_a \text{ cm}^{-1}$$

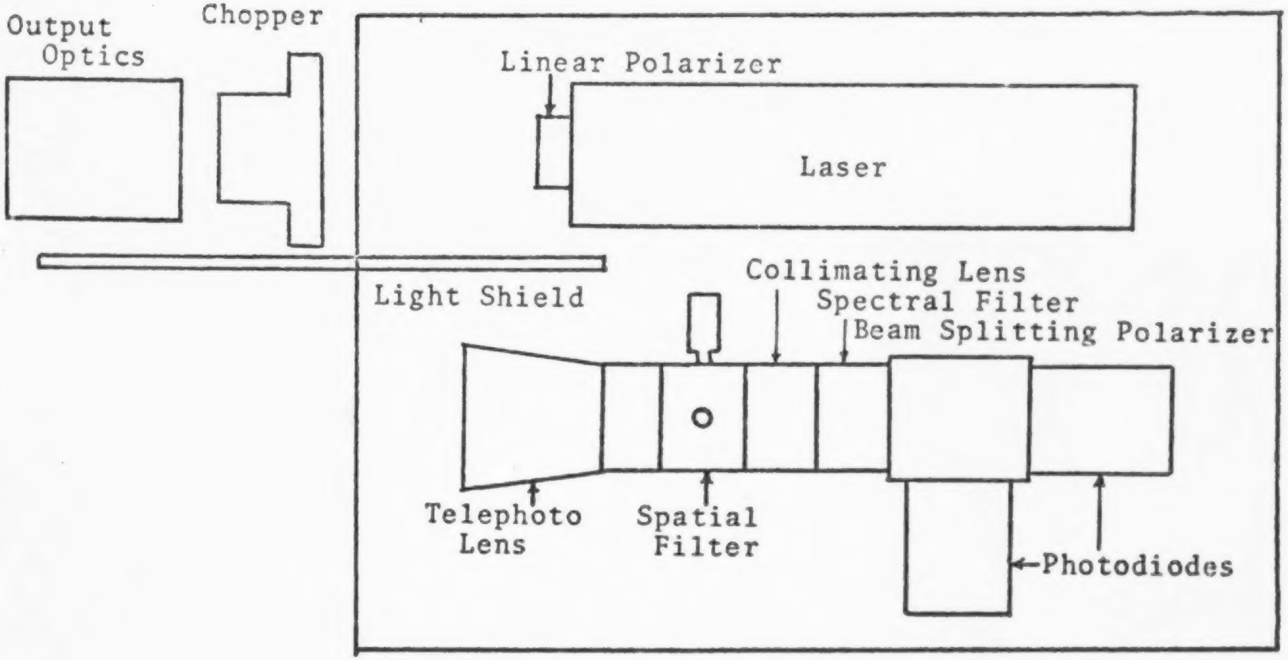

Figure 1 - Schematic diagram of Lidar Polarimeter.

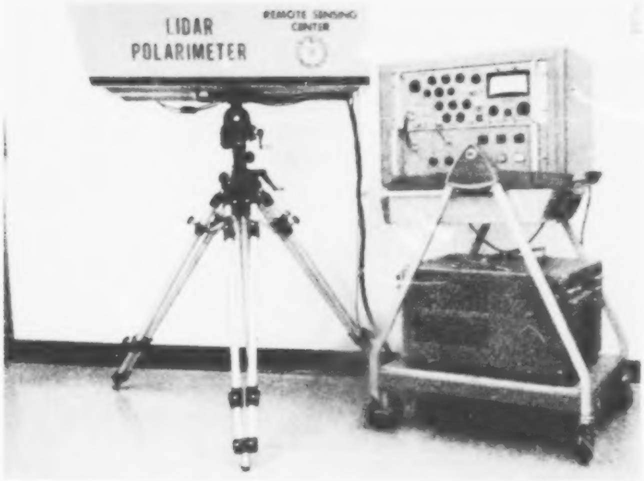

Figure 2 - Lidar Polarimeter.

where ρ_s = weight (grams) of teflon per cc of solution

ρ_a = weight (grams) of dye per cc of solution

The like and cross polarization backscattering cross sections were measured for a range of scatterer and dye concentrations at beam incidence angle of 23°. The beam diameter at the water surface was 1.5 cm. The results are shown in Figure 3. These data confirm the validity of the theoretical contention that depolarization is exclusively a volume scatter process and that the depolarization is proportional to the density of the particles in the subsurface volume. However, it is also clear that the absorption affects the data significantly, and that direct correlation between the laser return and the scattering particle density cannot be expected without *a priori* knowledge of the absorption factor.

The second solution consisted of water and an ordinary casein solution which contained a wider size range of scattering particles of random shapes. Dye was also used in the solution to establish a beam extinction length less than the depth of the container. The dye concentration was 14.4 mg of nigrosine black dye per liter of solution. Concentration of scatters from 23 ml

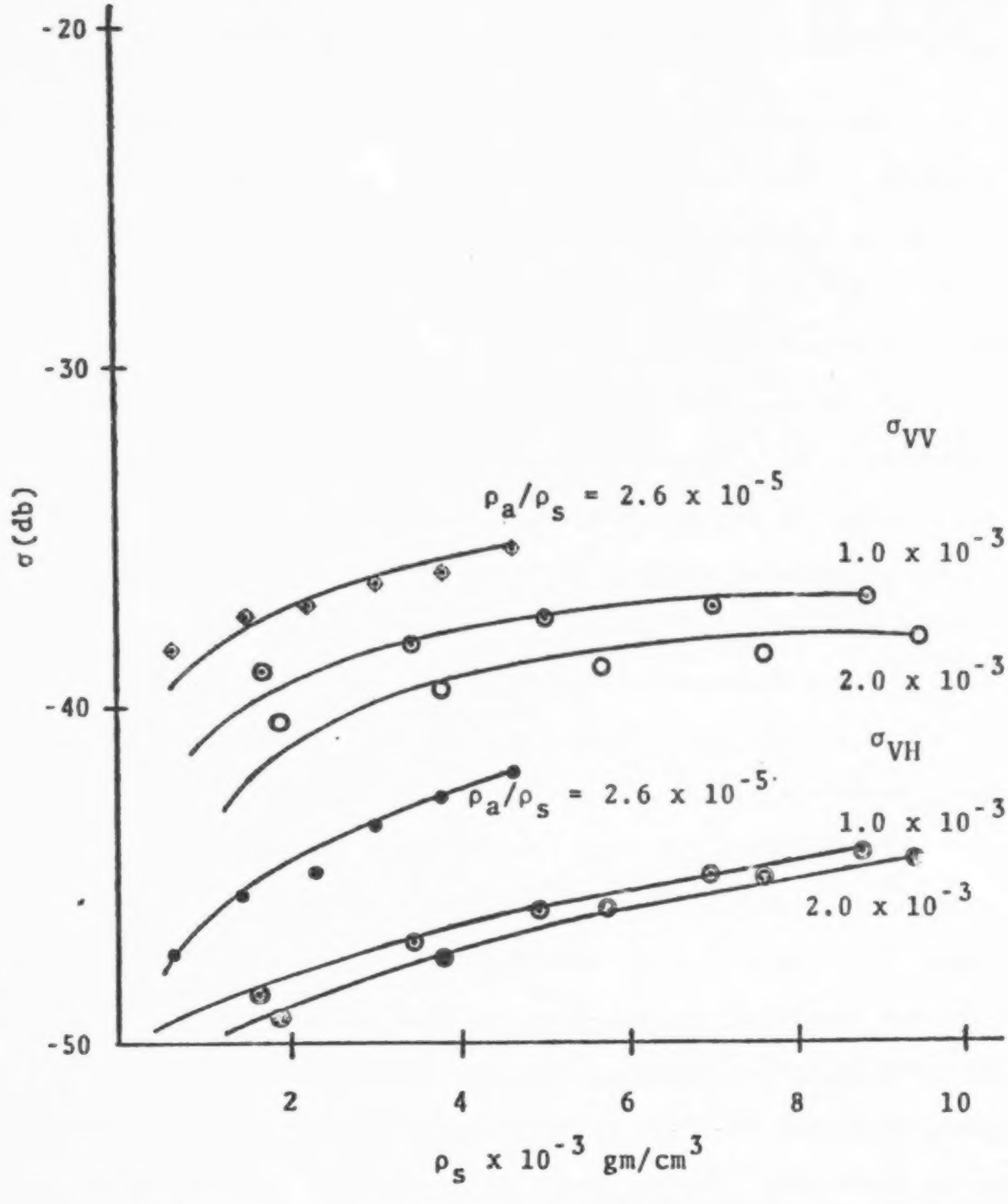

Figure 3 - Polarized and depolarized backscatter vs. mass concentration of scatterers. Angle of incidence equals 23°.

to 193 ml of scattering solution per liter of water were measured. The results are shown in Figure 4. These data were recorded with an incident beam diameter of 5 cm. This is a larger illumination field than was employed for the first solution and the measurements represent a stronger multiple volume scatter process. The results indicate almost total depolarization of the incident energy and a very small surface dependent scattering component. The data show a direct correlation with scatterer concentration, just as with the first solution.

The lidar polarimeter was also used to measure backscatter from a natural waterway. These measurements of an area of the Brazos River near Waco, Texas were supportive of the laboratory data. The river was measured over a period of several days and data were obtained from turbid water varying from 8.0 to 35.0 FTU. Measurements of total suspended solids varied from 10.0 to 50.0 mg/L. The transmittance varied between 70 and 94 percent. The laser like and cross polarized backscatter measurements were linearly related to these water parameters. The average measurements from the river water were similar to the data obtained in the laboratory using a teflon

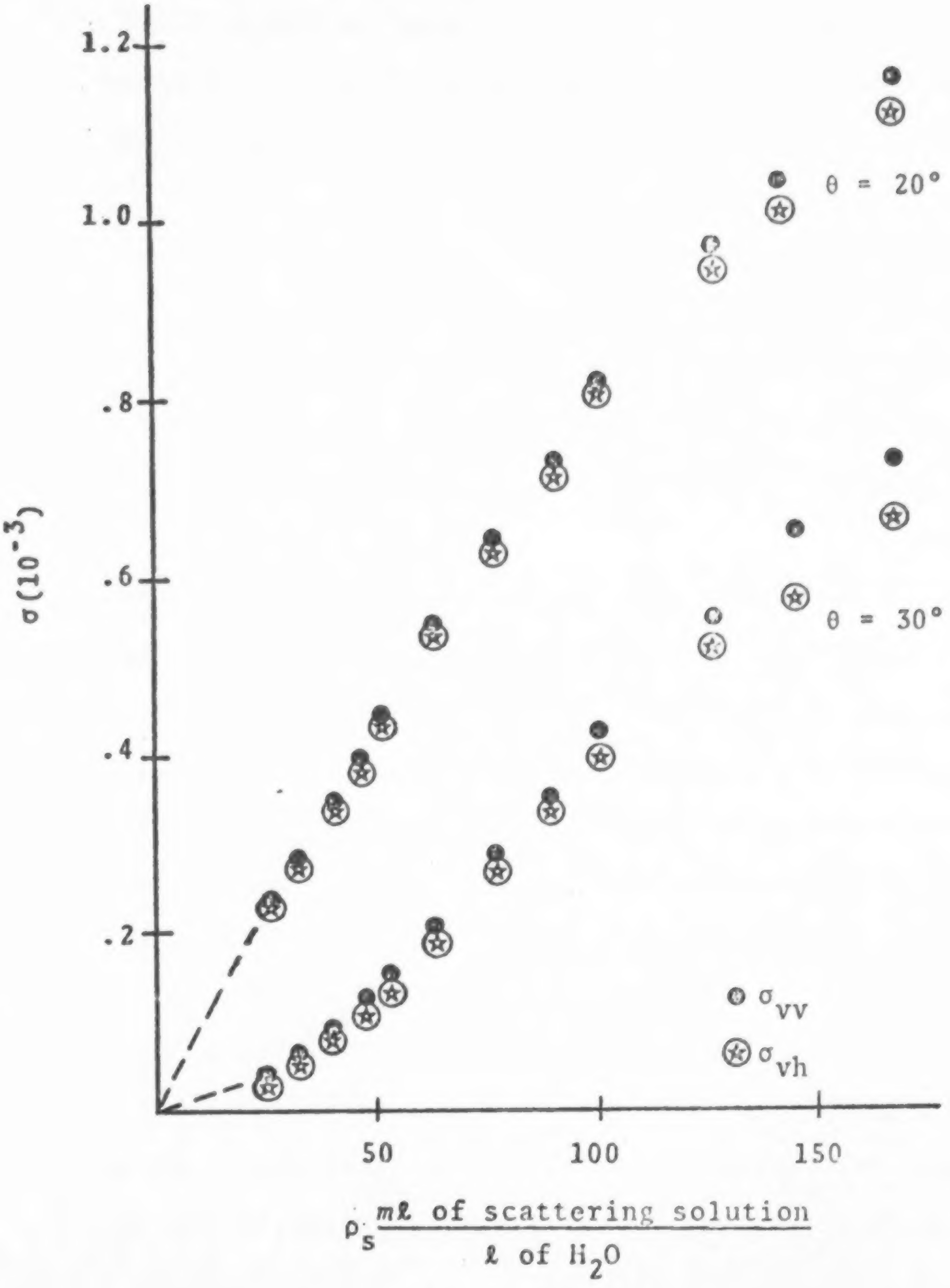

Figure 4 - Polarized and depolarized backscatter vs. mass concentration of scatterers.

scatterer density of approximately 1.0 mg/cm^3 without the absorbing dye.

MEASUREMENTS OF ROUGH SURFACE DIELECTRICS

The turbid water measurements described were made for smooth water surfaces. An additional experiment was performed to determine the effect of rough surfaces on the volume-dependent backscatter. The targets employed consisted of several samples of dielectric casting resin containing varying pigmentations. The samples provided a range of surface roughnesses from very smooth to height deviations of approximately 60 wavelengths. The varying pigmentations simulated the several scatterer-dye combinations used in the turbid water experiments. The pigmentations range from black, representing high absorption and negligible volume scatter, to white, representing large volume scatter and negligible absorption. A comparison of the backscatter from these samples is shown in Figures 5 and 6. Two factors are obvious from these measurements. First, the backscatter behavior is as expected from the turbid water measurements. That is, the depolarization is volume-dependent and is strongly influenced by the absorptivity. Second, the volume-dependent depolarization

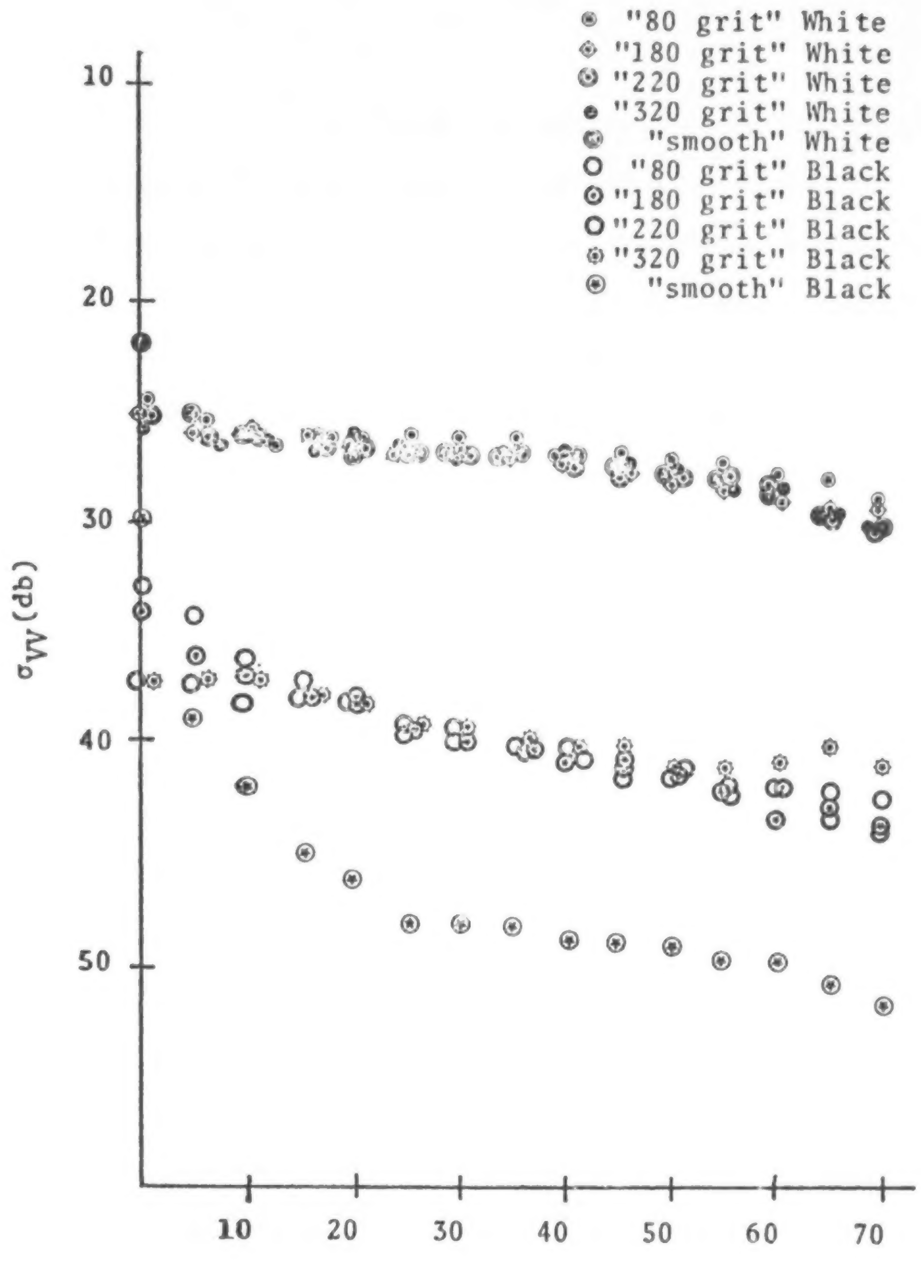

Figure 5 - Vertically polarized data for the white and black samples for all five surface roughnesses.

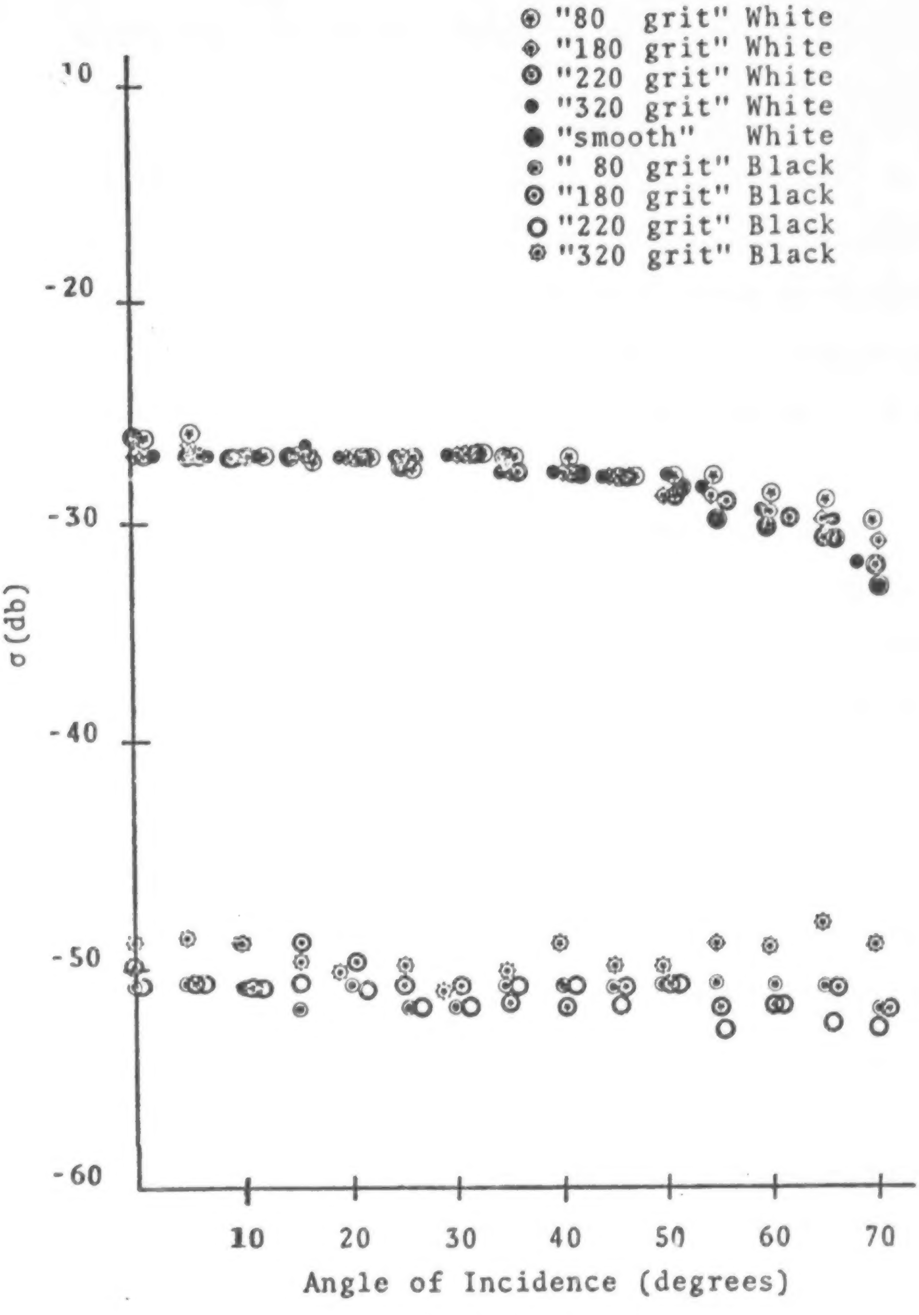

Figure 6 - Depolarized data for the white and black samples for all surface roughnesses with vertical transmit polarization.

component is virtually independent of surface roughness.

DETECTION OF OIL ON WATER

The preliminary experimental results indicate a potential for the use of the lidar polarimeter for remote measurement of certain water quality parameters. There is also reason to believe that the techniques can be employed to detect the occurrence of oil spills on turbid water.

The problem of describing the electromagnetic backscatter from an oil-on-water medium can conceivably be handled by combining the physical optics approach to describing scatter with an established layered media model. Generally, an oil layer is spatially inhomogeneous. In addition to these inhomogeneities, an oil layer apparently differs from the conventional layered media models in that the common "layer effect" normally giving rise to an interference phenomena is of secondary importance due to the non-uniform thickness of the layer.

Lidar polarimeter measurements of 1 mm thick layers of heavy and medium crude oil, kerosene, and gasoline indicate that a layered media model assuming the layer to act as a lossy dielectric is appropriate. That is, these substances contribute little backscattered energy, rather the principal contributing source of backscatter is from within the volume of the underlying water. Measurements of refined motor oil (SAE 30) however, show it to have a significant volume scatter term due to multiple scatter within the oil layer. Backscatter from this oil type is almost two orders of magnitude greater than any other petroleum product tested.

The model under development for use in describing the oil-on-water medium consists of three primary components:

1. An oil-air surface scattering component controlled by the index of refraction of the oil (approximately 1.45) and the surface roughness. This term has the same polarization as the incident energy, however the term should be small for incidence angles above about 20°.
2. A volume-dependent component from within the oil layer. This term exhibits depolarization and is highly dependent upon the oil type. The term will be small for most oil types.
3. A volume-dependent component from within the subsurface water volume. This term exhibits

depolarization; is highly dependent upon the density of suspended particles; and experiences an attenuation proportional to the oil thickness and dependent upon the oil type.

Each of these terms adds incoherently to the total backscattered power received for each polarization, that is:

$$P_{ii} = P_s + P_{oi} + \gamma P_{wi}$$

$$P_{ij} = P_{oj} + \gamma P_{wj}$$

where:

P_{ii} = like-polarized backscatter

P_{ij} = depolarized backscatter

P_s = oil surface term

P_o = oil volume term

P_w = water volume term

γ = attenuation of oil layer (two-way)

DUAL-WAVELENGTH LIDAR POLARIMETER

The potential for detection of oil on water using a monochromatic (633nm) lidar polarimeter depends upon the effect of the change in the index of refraction and the added attenuation of the oil layer over the water volume. Initial tests show that the presence of oil does alter the like and cross-polarized backscattered return, but that oil cannot be uniquely differentiated from certain turbid water conditions. To improve the detection reliability, a record generation lidar polarimeter is being constructed for the Coast Guard which employs two lasers (633nm and 441.6nm). The shorter wavelength source takes advantage of the marked increase in the index of refraction of many oil types in the blue region. The two wavelength system increases the separability of turbid water classes and oil types, and provides potential for determination of oil thickness.

This system has the added feature of real-time classification of the lidar polarimeter signals. The signal processor is a special purpose digital computer capable of immediate analysis of the water condition through the implementation of appropriate classification algorithms. The real-time signal classification technique was developed by Texas A&M University for the Naval Ordnance Laboratory for use in real-time classification of sea ice using an airborne radar sensor.

CONCLUSION

Measurements of laser light backscattered from inhomogeneous media confirm the theoretical prediction that depolarization is a subsurface volume scatter process which is dependent upon the density of suspended particles in the volume. This effect has been utilized in the measurement of the turbidity of water and in the detection of oil on water. A new remote sensing device is under development to employ this potential for remote, continuous, day-night surveillance of water surfaces to automatically identify a range of petroleum and petroleum byproducts and other contaminants.

ACKNOWLEDGEMENT

The dual wavelength Lidar Polarimeter is being developed for the Coast Guard under contract DOT-CG-34017-A. "The opinions or assertions contained herein are the private ones of the writer and are not to be constructed as official or reflecting the views of the Commandant or the Coast Guard at large."

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Progress Report

DETECTION OF DISSOLVED OXYGEN IN WATER THROUGH REMOTE SENSING TECHNIQUES

By Arthur W. Dybdahl

Abstract

The technique of detecting dissolved oxygen concentrations in the country's waterways with airborne remote sensing is discussed. This technique was developed at the National Field Investigations Center (NFIC), Office of Enforcement and General Council, EPA, Denver, Colorado. The recording media and data processing are explained. Experimentation is presently under way to quantify the airborne reconnaissance data so that concentrations of dissolved oxygen to within 1 to 2 parts per million can be readily obtained. A brief discussion of the water parameters that cause interference with the utilization of this technique are discussed.

Progress Report

DETECTION OF DISSOLVED OXYGEN IN WATER THROUGH REMOTE SENSING TECHNIQUES

INTRODUCTION

There is a great need present for a technology to be used in the rapid assessment of water quality parameters in large and small bodies of water throughout the country. This technology will be developed and applied to practical operations through remote sensing techniques. Qualitative detection of water quality parameters, such as turbidity, suspended solids, dissolved solids, and color, are presently at hand with the use of airborne cameras and passive scanners. There is a paramount need to quantify remote sensing data in terms of the water quality parameters for enforcement and monitoring applications. The development of a quantitative detection mechanism for dissolved oxygen in water is a beginning in this enormous task.

APPLICABLE OPTICAL PROPERTIES OF WATER

A great deal of effort has gone into the measurement of the optical properties of water since the mid-1940's. Samples of distilled water, in addition to those obtained from the oceans, coastal, and bay (estuarine) waters, have been thoroughly tested for optical transmittance and reflectance properties. Distilled water has the maximum transmittance values in the bandwidth from 400 nm to 650 nm. Ocean water is the next in line with a noticeable decrease in transmittance from 400 nm to 550 nm. Coastal and bay waters display significantly lesser transmittance values than that of the ocean waters (Specht[1]). The data for the attenuation (Mairs[2]) and the extinction (Hale[3]) properties of water are also collectively available.

The transmittance data for the four above mentioned types of water is plotted in Figure 1.[1] This data was measured for a water path length of 10 meter. Note that the loss in transmittance is far greater in the 400 nm to 460 nm region (blue) than the green region (460-575 nm). this is an important feature used in the detection of dissolved oxygen in water.

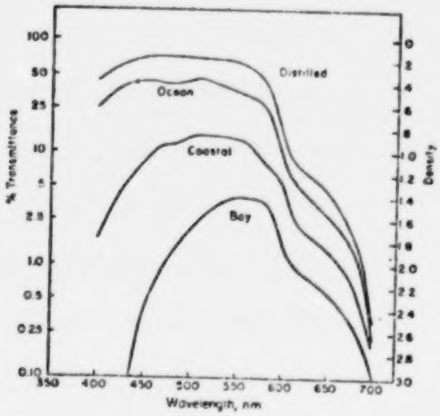

FIG. 1. Spectral transmittance for ten meters of various water types.

THE AIRBORNE DETECTION TECHNIQUE

Recording Technique

The technique for the airborne detection of dissolved oxygen in water was found and developed through empirical data rather than through any deep-thought scientific formalism.

This technique was discovered in late 1970. It has been under continual expansion, testing, and field verification since that time.

The recording medium aboard an aircraft is a camera, Kodak 2443 false color infrared film and a Wratten 16 orange gelatin filter. The exposure is set on the camera at approximately 1/4 to 1/3 f-stop, less than the so-called normal exposure. This sensor renders healthy water, saturated with dissolved oxygen, as a bright-brilliant blue. It renders septic (near zero dissolved oxygen waters) virtually black, or more precisely, the characteristics of unexposed processed film.

The film is processed with the usual EA-5 chemicals and procedures.

Field Verification of Film Indications

In an attempt to optically explain the above film indications, visual and hand-held photographic observations were carried out during EPA Water Quality Surveys, in areas where saturated and septic waters were being tested. Saturated waters were quite clear with the bottom visible to depths of 8 to 10 meters The overall color of this type of water was greenish-blue. Septic waters were nearly opaque as far as depth penetration and displayed a very dark gray-green color. These waters were known to be subjected to a very high biochemical oxygen demand (BOD). This field data supports the water transmittance curves shown in Figure 1.

Film Interpretation and Analysis

Recalling the false color rendition properties of the Kodak 2443 false color infrared film, any natural green scene will record as blue, assuming the absence of chlorophyll substances which photographs as red. Waters saturated with dissolved oxygen photographed in a bright-blue color. As the oxygen demand increases, the dissolved oxygen is decreased, the bright-blue color of the water, recorded in the film, gradually progresses through a dark-blue to black. By staying in the linear portion of the film characteristic curves, it is a reasonable assumption that the optical response of the target being photographed will be recorded linearly. This "blue-to-black" indication results from the optical absorbance in the green region, being increased as the dissolved oxygen concentrations decrease. This technique does not work in the region from 0.6 microns (600 nm) to 1.0 microns

(1,000 nm) which is the red and near-infrared portions of the optical spectrum.

Several areas throughout the country have been flown commensurate with the gathering of detailed ground truth. The dissolved oxygen data from the ground truth has been used in an attempt to calibrate the "blue-to-black" curve resulting from densitometric measurements made upon the exposed aerial film. Initially only the data from two bay areas having equal water temperatures at the time of flight, was used for the calibration procedure. Septic waters appear black in the film densitometrically identical to the unexposed film area between frames. The task of calibration is to identify film density data with the precise area of ground truth. Blue, green, yellow, and red density measurements were made on the film with a Macbeth TD-203AM Transmission Densitometer. The density data was compared to the ground truth. The variable color parameter is blue (density). The data is then plotted. One such calibration curve is shown in Figure 2. The ground truth was used to establish the position of each straight line. The abscissa of Figure 2 is the film density. It is commonly defined as:

$$D = \log_{10}\left(\frac{1}{T}\right) \quad (1)$$

where T is the transmittance of the particular area on the film under test, for a particular color filter (red, green, or blue). It is easily seen that the dynamic range in film is greater than 1000:1. The ordinate represents the concentration of dissolved oxygen in parts per million (ppm) or milligrams per liter (mg/1). The range on this parameter has been limited to 0 to 10 ppm because in the natural environment the dissolved oxygen levels rarely exceed 10 ppm. To exceed this value usually indicates supersaturation accomplished by water pouring over rapids or in close proximity of an aerator. In bodies of water containing large amounts of aquatic plant growth (in the summer), the dissolved oxygen concentrations can reach, or even exceed, the saturation limit in the mid-afternoon hours, the period of maximum oxygen production.

Any test method has inherent problems with interference phenomena. This one is no exception. Waters in the natural environment contain finite amounts of suspended solids and organic waste materials. The impact of the materials upon the optical transmittance properties of various types of natural water is readily seen (Figure 1). The above mentioned materials contribute a yellow to light-red cast to water. When this is superimposed with the natural bluish-green color of oligotrophic-type waters, the blue cast is decreased and the water becomes predominantly green (Figure 1). Since deep yellow to red materials photograph green in the false-color infrared film, the green transmittance factor becomes an important one as a base line for each particular area of water under test. Red is not used in conjunction with this film because of the sensitivity of the cyan emulsion layers to the near-infrared region (0.7μ to 1.0μ). This would create an additional interference factor when aquatic plant growth is present and would not represent a reliable base line. So, through the optical inspection and analysis of over 1,100 data sets (red, green, and blue form a set for each point on the film) three color parameters have been established for calibration purposes. They are:

(1) Blue
(2) Green
(3) Blue-minus-Green

The parameter denoted by (3) has been chosen, as opposed to "Green-minus-Blue" to eliminate having to use negative irrational numbers. Again, the green parameter establishes the suspended solid material influence in the water under test. The initial density/ground truth data is plotted for the blue and green parameters. Then the actual calibration is carried out with "Blue-minus-Green" density value plotted with the concentration of dissolved oxygen. This plot is usually referred to as a difference curve. The difference curve for the data sets given in Figure 2, is provided as Figure 3. In practice, the concentration vs. density data is programmed into a computer. Two data sets are required. They are the Blue and Green density values for the point on the film corresponding to the physical location of the ground truth and for the unexposed (between frame) film. The latter eliminates the influences of base fog if any is present. The computer then calculates the equations of the three straight lines. This is done by using the point-slope form of the equation of a straight line in two dimensions. This is accomplished by the data points $P_1(x_1,y_1)$ for high dissolved oxygen, and $P_2(x_2,y_2)$ for zero dissolved oxygen, and

$$y = \frac{dy}{dx}(x - x_1) + y_1 \tag{2}$$

where $\frac{dy}{dx}$ is the first derivative of the equation for the line and is equal to $(y_2 - y_1)/(x_2 - x_1) = M$. The expressions for the Blue and Green lines in Figure 2, respectively, are:

$$y_{Blue} = 2.655x_{Blue} + 10.462 \tag{3}$$

$$y_{Green} = 3.715x_{Green} + 10.866 \tag{4}$$

where x_{Blue}, x_{Green} are the blue, green film densities, respectively

y_{Blue}, y_{Green} are dissolved concentrations for the blue, green lines, respectively, in parts per million (ppm).

The expression for the difference line is calculated from this data, which for Figure 3 is:

$$y = 9.307(1 - x_{\Delta}) \tag{5}$$

where x_{Δ} = blue-minus-green density and

y = dissolved oxygen concentration in ppm.

To use the calibration curve in Equation (5), the blue and green data pairs are supplied to the computer. It calculates the value of Blue-Green value (x_{Δ}) and finally the dissolved oxygen concentration, designated by y.

The relative uncertainty of y can be calculated from Equation (5).

$$\left|\frac{dy}{y}\right| \approx \left|\frac{dx_{\Delta}}{x_{\Delta}-1}\right| \tag{6}$$

where the vertical lines signify absolute values, $|-x| = x$. The absolute uncertainty for a given calibration curve is:

$$|dy| = |-9.307dx_{\Delta}| \tag{7}$$

If $dx_{\Delta} = 0.02$, the accuracy of the Macbeth densitometer, then $|dy|$ is 0.186 ppm. The variance is given as $|dy|^2 = 0.0345$.

Hundreds of data points for healthy waters, with insignificant discoloration and suspended solids have been plotted against the calibration curve in Figure 3. The points all fall within 1 ppm of the line.

It must be mentioned that one must be cognizant of the inherent errors of the field equipment used in obtaining the dissolved oxygen phase of ground truth. Some types of systems are consistently off by as much as 1 ppm. This error must be compensated for in order to produce an accurate calibration curve.

Significant Affects Upon the Calibration Curve

A. Film Exposure

Film exposure levels can have a significant affect upon the slope of the calibration curve. Over-exposure with the same calibration curve, results in a lesser dissolved oxygen concentration than is actually present. Likewise, under-exposure results in a greater concentration than is actually present. For this reason, a new calibration curve based upon the inherent film exposure at the center of a photographic frame near the intersection of the fiducial marks, is generated for each mission location.

B. Lens/Illumination Effects

A KS-87B aerial framing camera is used on all OEGC missions. It has a 152 mm lens cove assembly with a lens fall-off characteristic curve of $\cos^{12}\theta$, where θ is the angle off the principal axis of the lens. A plot of exposure vs. distance across the film format will reveal the effect of the lens fall-off.

There is one more factor that integrates with the lens fall-off to influence the optical irradiance across the film format. This factor is the solar illumination function. If I_o is the optical energy level at the center of the film format, then the optical energy distribution across the film format is:

$$I(\lambda) = I_o(\lambda)\int_o^\theta L(\theta,\lambda)S(\theta,\lambda)d\theta \tag{8}$$

where $I(\lambda)$ = optical energy distribution across the film format as a function of wavelength λ.

$I_o(\lambda)$ = optical energy at the center of the film format as a function of λ.

$L(\theta,\lambda)$ = lens fall-off function $(\mathrm{Cos}^{12}\theta)_\lambda$

$S(\theta,\lambda)$ = Solar illumination function

$S(\theta,\lambda)$ can easily be normalized to one yielding a relative energy weighting factor. Camera lenses usually possess a spherical symmetry that eliminates an integration factor which encircles the principal axis.

One will normally see a bright spot in or near the center of the frame of film. Densitometer data are limited to a circle whose radius is 1 cm about the center of the bright spot for a 4.5" by 4.5" format. Data taken anywhere else in the frame must be normalized to this spot to render correct indications from the calibration curve.

C. Water Body Characteristics

Areas of significant discoloration in water would be expected to significantly influence the effectiveness of the calibration curve. Many sources of discoloration result from municipal and industrial outfalls and high turbidity or suspended solids. An investigation has been carried out over a submerged diffused lignin sulfonate discharge located at Port Angeles, Washington. In the true-color ektachrome aerial imagery, the effluent was dark-gray reddish-brown in color. Ground truth indicated no dissolved oxygen depression within the area of influence of the resultant plume. The blue and green densitometric data and ground truth data were used to plot the respective straight lines in Figure 4. The difference curve was also plotted in Figure 5. This curve was compared to the blue calibration curve in Figure 3. As an example, if $x\Delta$ in Figure 5 were 0.125 corresponding to 8 ppm, then the equivalent value in Figure 3 would be 8.25 ppm. In the range from 8 to 9.5 ppm of dissolved oxygen, the correlation was less than 0.3 ppm in spite of the significant discoloration.

Future Studies Required

To enhance the integrity of this technique, many questions must still be answered. Several will be discussed in the next few paragraphs.

A. First it must be determined if the observations of green absorbance are physically due to the presence of dissolved oxygen. Testing will begin later this fall in the Environmental Physics Laboratory at NFIC-Denver. An optical test cell whose path length through a particular medium can be adjusted from 5 to 50 meters, has been designed and is awaiting fabrication. It will require only 2.7 liters of water sample. Under laboratory conditions, dissolved oxygen depressions can be induced into a particular water sample and optically monitored to document its behavior in the green region. This program will establish the optical properties of many types of natural and waste waters as a function of dissolved oxygen concentrations.

B. The effects of water temperature upon the concentrations of dissolved oxygen in the optical recording medium will have to be studied. This will involve effort in both the laboratory and in the field.

C. The function of water depth and the optically generated concentration values must be determined. This can also be accomplished, for the most part, in the Physics Laboratory.

D. Other recording media must be examined to possibly provide more reliable concentration data. Kodak 2443 film with a Wratten 58 green filter has been quite successful although in limited use. This technique must be expanded into the domain of active and passive sensors. It is worth noting that this spectroscopic technique has been carried out on an aerial true-color ektachrome film SO-397. The results showed that the Kodak 2443 film provided much better color separation because of its false-color rendition.

E. Natural and induced interferences with the detection of dissolved oxygen in all water environments must be explored. These include the discoloration and suspended solids produced by man-made and natural sources. Many of these can be effectively studied in a laboratory.

F. The calibration curve must be further tested and retested in order to statistically validate its integrity. To date most of the ground truth data/calibration curve correlations have been carried out in the concentration range of 7.0 to 9.5 ppm. The curve needs to be studied further in the range from 0 to 7.0 ppm.

Finally, the technique must be adopted to night aerial reconnaissance, which will undoubtedly involve an active light source and absorption spectroscopy. This will add greatly to a round-the-clock enforcement monitoring capability.

SUMMARY AND CONCLUSIONS

A technique for the quantitative detection of dissolved oxygen concentrations in water through remote sensing has been discussed. The recording medium has been an airborne framing camera employing Kodak 2443 False-Color Infrared film with a Wratten 16 (orange) optical filter. Through a densitometric analysis of the exposed film together with ground truth, a calibration curve has been generated. This technique has provided an accuracy of better than ±1ppm in healthy bay and ocean waters.

Future efforts to improve the technique under all conditions was discussed. This will involve studying the influences of water temperature and depth, discoloration and suspended solids upon the quantitative results.

Acknowledgements

The author wishes to acknowledge the support received from the Surveillance and Analysis Division, Region X, EPA, Seattle, Washington; and the State of Washington, Department of Ecology, in obtaining ground truth for the many flights conducted in the Puget Sound area.

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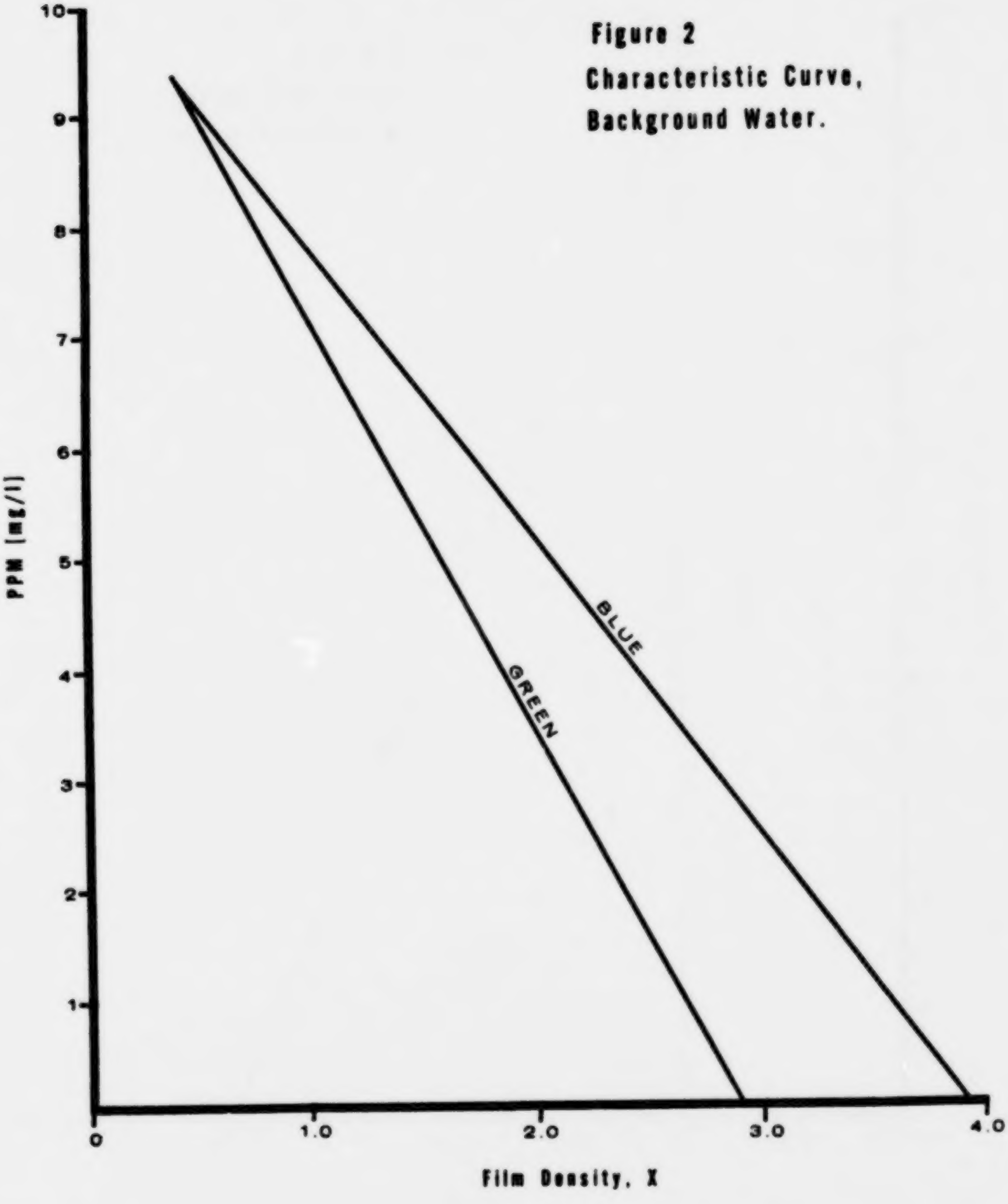

Figure 2
Characteristic Curve,
Background Water.

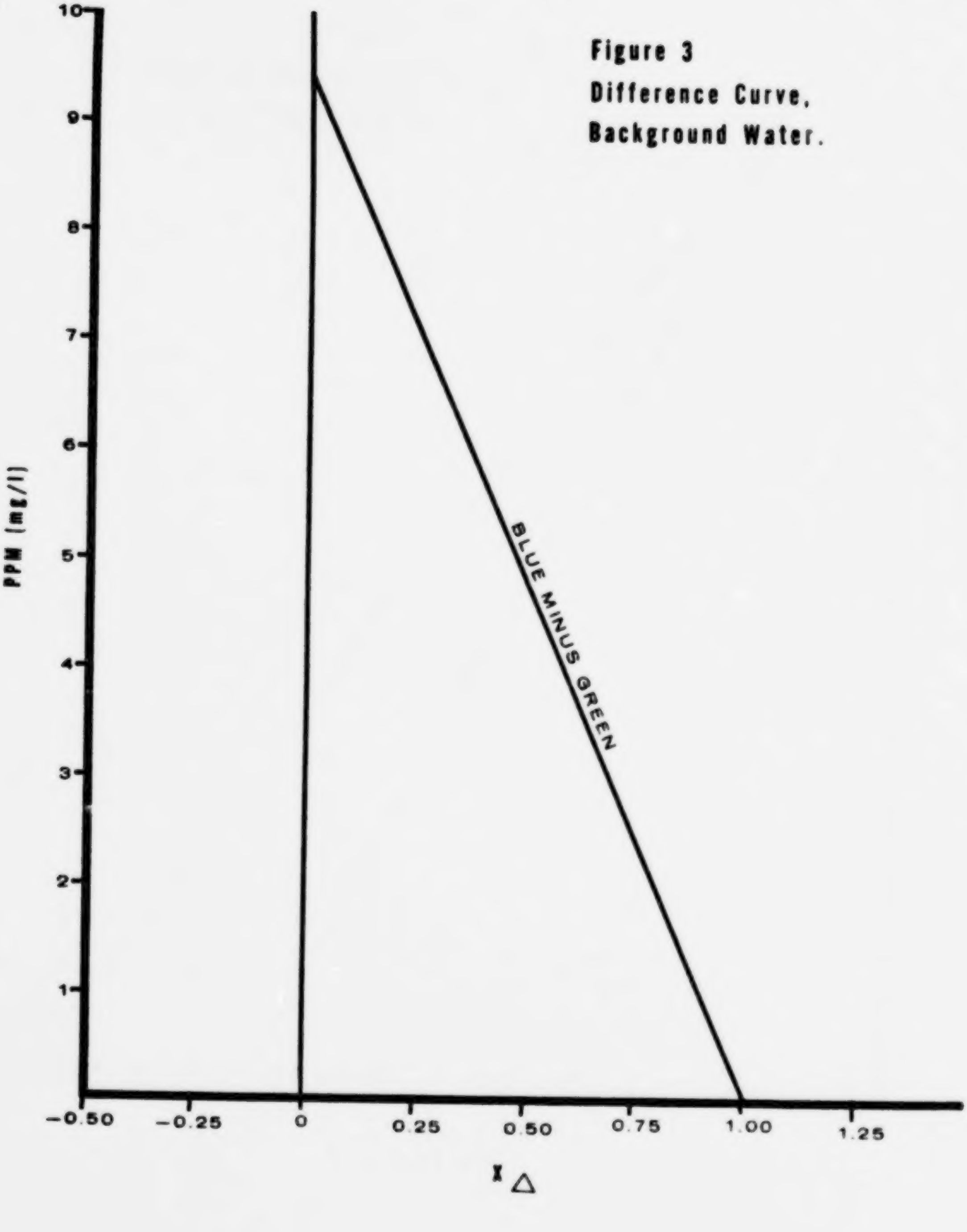

Figure 3
Difference Curve,
Background Water.

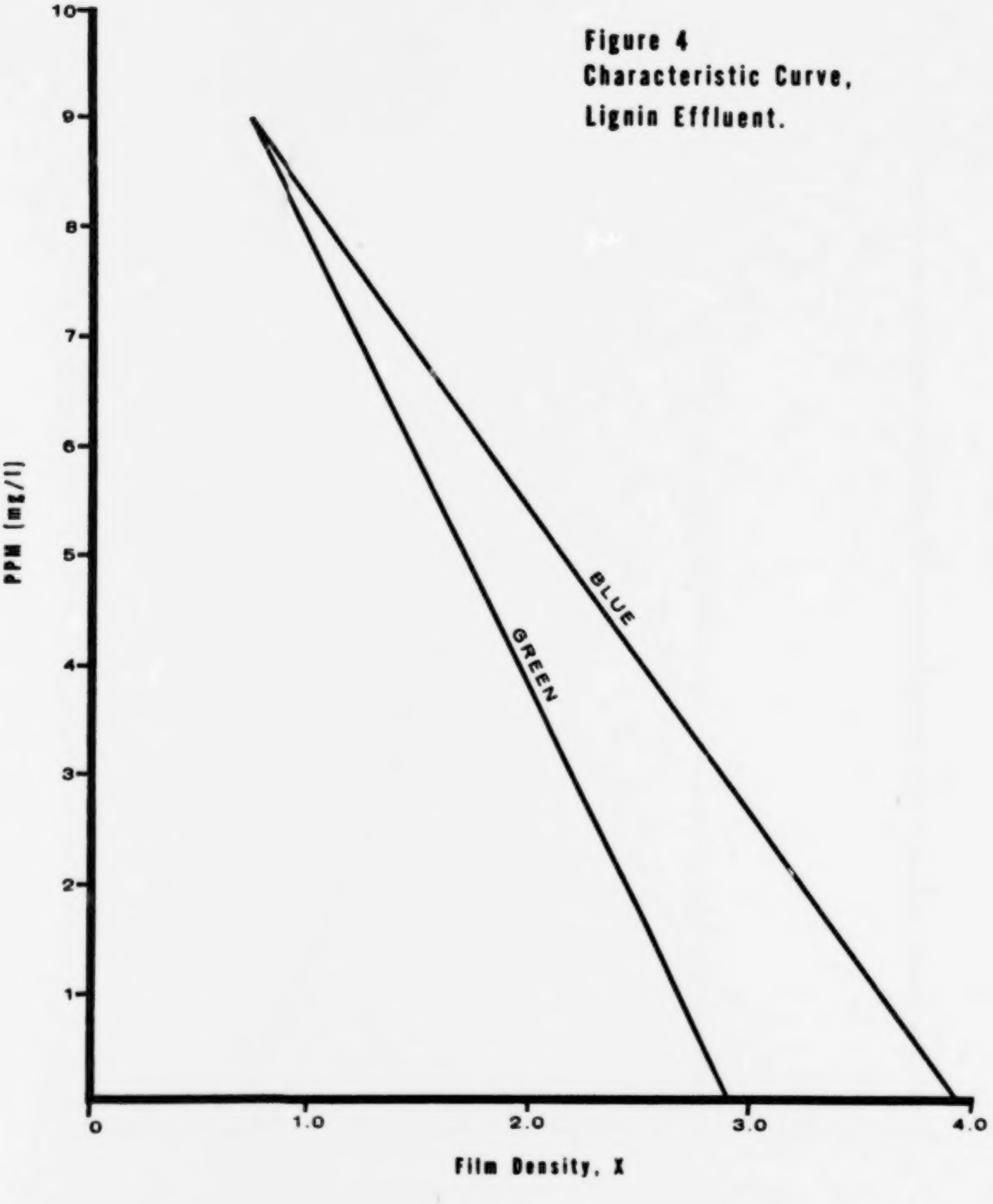

Figure 4
Characteristic Curve,
Lignin Effluent.

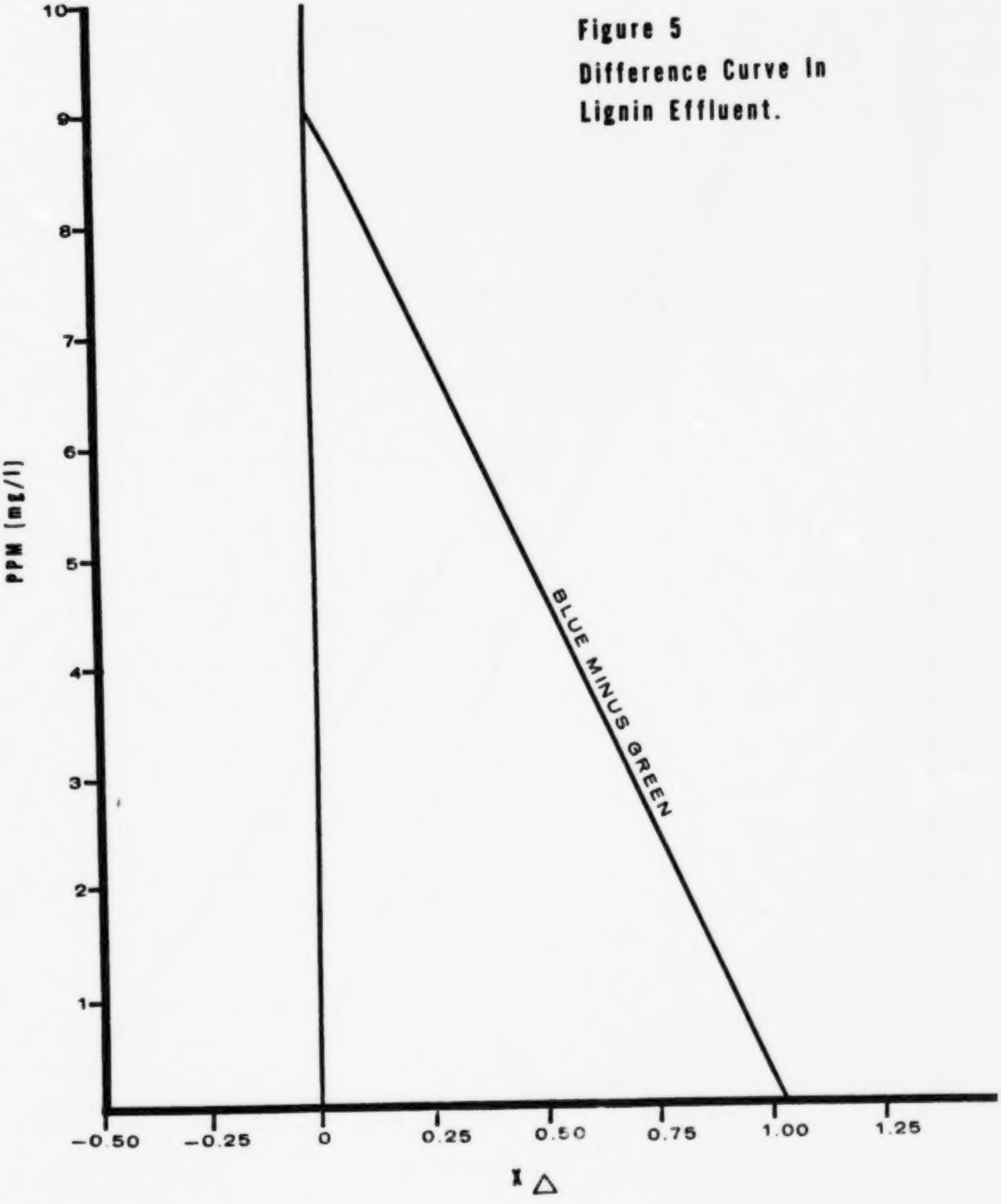

Figure 5
Difference Curve In Lignin Effluent.

A SEARCH FOR ENVIRONMENTAL PROBLEMS OF THE FUTURE

by

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and James R. Hibbs*

for
presentation at

EPA'S SECOND CONFERENCE ON
ENVIRONMENTAL QUALITY SENSORS
NATIONAL ENVIRONMENTAL RESEARCH CENTER

Las Vegas, Nevada
October 10-11, 1973

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ABSTRACT

Just as changes in key indicators of environmental quality require monitoring and prediction through a network of physiochemical sensors, so too must changes of a technical, economic, or social nature which impact significantly upon the environment be identified. Effectively information needs to be brought to the attention of appropriate agencies early on new and rapidly developing processes, technologies, commodities, or events which threaten serious environmental consequences. This paper describes the results of a program initiated by EPA to serve just such a purpose.

To identify future problems, a search was initiated of three broad categories of human activity: (1) technical production activities by reference to the Standard Industiral Classification (SIC) system, (2) areas of environmental concern selected by reference to known areas of EPA involvement, and (3) societal trends or changes relating to current social, economic, political, and institutional events. This approach resulted in the development of a preliminary list of problem statements and stressors. Using a set of ranking factors, these statements were culled to produce a list of ten "most serious" problems. These problems were then projected 5-10 years into the future with respect to magnitude, effects, and consequences.

Conclusions are presented regarding the efficacy of this approach toward prediction of environmental hazards for EPA program planning purposes.

A SEARCH FOR ENVIRONMENTAL PROBLEMS OF THE FUTURE

Introduction

At any one point in time, EPA resources are allocated across a spectrum of identified environmental problems. The planning process, which results in such allocations, requires a continuous input of new information on (1) the extent that these resources are yielding effective solutions to existing problems, and (2) changes of a technical, social, or economic nature which will create new problems or significantly magnify existing problems. This paper describes some of the results of a study(1) aimed at supplementing EPA inputs of the latter type, i.e., changes occurring now which will have significant environmental impacts in the near future requiring EPA's attention. Some of these future problems have their origin in current EPA programs, e.g., implementation of environmental controls, while others are a consequence of rapidly expanding production-consumption activities, the introduction of new products, processes, or activities, or changing social conditions.

In this study an effort was made to identify short (5 year) and intermediate term (10 year) problems. It was a preliminary attempt at a systematic examination of several categories of human activity from whence such problems might arise. Problems of a national, as opposed to regional or local, nature were sought although the tools employed are applicable to regional or local use. The broad scope of the potential problem areas, time limitations, and sheer necessity precluded more than a cursory review of the activity categories selected. Consequently, the authors make no claim to completeness.

Ten problems, considered to be "most serious" were selected from a list of identified candidate problems for amplification with respect to magnitude and effects. A priority ranking scheme provided the means to select these. The ten problems identified are felt to be of national importance within the next 5-10 year time frame, and serious enough for consideration by EPA in assigning agency priorities in coming years.

Development of Candidate Problems

Three categories of human activities formed the starting point for identifying candidate problems. These were

(1) Sectors of Industrial Production Activity

(2) Sectors of Environmental Concern

(3) Sectors of Societal Change and/or Trends.

These three categories were screened over a five week period employing the literature, EPA and Battelle resource personnel, and other sources. Each category was screened independently in a systematic manner. Thus the Standard Industrial Classification (SIC) system was utilized as a reference for the technical production category. Broad sectors (2 digit SIC codes at most) were examined. Environmental sectors reviewed were (1) legislation, (2) ongoing R&D in air, water, and land media, (3) health effects and specific pollutants, (4) pollution control technology, (5) monitoring and standards, and (6) transport processes. Societal sectors selected for examination included demographic, crime, medical science, education, social, economics, international, technological, government, urban, and labor.

Each category yielded a list of candidate problems expressed as a problem statement with a number of "stressors" identified. These stressors were specific pollutants or classes of pollutants--chemical compound or element, biological agent of physical substance--which have an adverse impact on the environment. The repeated occurrence of a given stressor in a list of candidate problems itself suggested a pollution problem of major concern. For example, heavy metals and toxic organics were frequent stressors in candidate problems.

The preliminary lists generated from the three independent category searches were culled and combined into one single list of problem statements. It was found that these could be grouped in the following nine general areas:

- Pollution control residues
- Industrial production-consumption residues
- Energy supply
- Toxic and hazardous substances
- Air pollution

- Water pollution
- Ecological effects
- Radiation and sound
- Social.

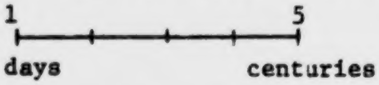
Many problems of course related to more than one of these areas.

Selection and Ranking of Serious Problems

A set of nine factors each with a value scale of 1 to 5 was developed for use in selecting and ranking ten "most serious" problems from the candidate problem statement data base. The factors included

(1) Physiological risk (toxicity)
(2) Persistence
(3) Mobility/pervasiveness
(4) Bulk or volume of substance
(5) Number of people affected
(6) Relative environmental/ecological complexity
(7) Relative technological complexity
(8) Relative social/political complexity
(9) Research needs.

For a given factor the perceived worst condition was given the value of 5. Thus, the scale for persistence was as follows:



It is noted that the first four factors are more related to ranking specific substances (stressors) whereas the last five are more suitable to ranking broader problem statements. Since each problem that was ranked has a number of associated stressors, the person performing the ranking had to make a judgement based on his perception of the relative importance of the various stressors involved. Obviously while such judgements could detract from the validity of the results, the use of such factors avoids totally subjective and biased priority setting. An attempt to weight the nine factors did not result in sufficient discrimination to merit the use of weighted factors.

The nine factors were applied in two steps: the first of which was to rank the initial list of candidate problem statements. Ten "most serious" problems were derived from this ranked list. It was convenient in several cases to combine two or more problem statements which ranked high in importance on the ranked list. For this reason the ranking factors were applied a second time, and by a different group of Battelle professionals, to prioritize the resulting list of ten "most serious" problems. The resulting ten problems in order of ranking follow.

Ranking	Problem
1	Impacts of New Energy Initatives
2	Geophysical Modifications of the Earth
3	Trace Element (Metal) Contaminants
4	Hazardous and Toxic Chemicals
5	Emissions from New Automotive Fuels, Additives, and Control Devices
6,7	Disposal of Waste Sludges, Liquids, and Solid Residues
6,7	Critical Radiation Problems
8	Fine Particulates
9	Expanding Drinking Water Contamination
10	Irrigation (Impoundment) Practices.

Projections

It is apparent that the ten problems identified are quite broad in scope. This is a natural consequence of aggregating related problems with the objective of defining problems of national as opposed to regional or local importance. In projecting future magnitude and effects, time and budget limitations necessitated selecting only one or two facets of each problem for analysis. Thus, facets selected for projection were (1) definitely near- or short-term future problems requiring a solution, (2) those not already extensively examined by current scientific, social, or political institutions (e.g., AEC's study of radioactive releases from nuclear power plants), and (3) national in scope.

Examination of these ten problems in detail revealed several commonalities which, in themselves, could be the focus of EPA efforts. For example, the multimedia nature of several of the problems is apparent. For specific stressors, such as toxic heavy metals and organics, the extent to which these are transferred from one medium to another is fairly well documented. The adoption of pollution-control measures, resulting from environmental legislation, is a contributor to intermedia transfer.

The need for more information on sources, pathways, and effects, especially health effects, of stressors is an aspect common to several of the problems identified. Similarly the impact of specific stressors on ecosystems, while recognized, needs clarification in order that tradeoffs between man's need for material resources and environmental controls can be balanced.

A summary of the principal findings for each of the ten "most serious" problems follows.

Impacts of New Energy Initiatives

Problem. Current concern exists over the possibility of shortages over the next 5-10 years in energy resources. This concern is popularly referred to as the "energy crisis". Whether the crisis is due to actual resource limitations or the effects of institutional policies of the past (more probable), one fact appears fairly certain, viz., the energy demand of the U.S. is expected to nearly double between now and 1985. Meeting this demand will require major technological efforts, all having significant environmental impacts. The development of new energy technologies such as coal gasification, coal liquefaction, and oil shale and tar sand processes, is at an early stage. The impact of these will likely not be fully felt until a time greater than 10 years in the future. It is logical to examine these developments now with respect to likely environmental effects and incorporate controls as the technology develops. And, in fact, this is already being done as a consequence of increased public awareness of environmental issues.

Of more importance are the short-term pollution problems that will arise as a result of certain initatives being instituted today in anticipation of meeting actual energy and environmental needs within the next 10-year period. These problems include: (1) oil spill incidents from current and projected massive imports of foreign oil; (2) radioactive emissions and waste disposal needs from increased numbers of nuclear power installations; and (3) increasingly large volumes of solid residues from coal cleaning--needed to help meet SO_x emission limitations on coal powered electric plants. Of these three problems, only oil spill incidents will be projected here. The problems of radiation effects and disposal of pollution control residues from nuclear power production and coal cleaning are covered elsewhere. The environmental effects of coal gasification, oil shale, and other emerging technologies lie farther into the future than this program is aiming and it is assumed that their associated environmental consequences will be dealt with as the technology develops.

Magnitude. Estimates of oil import quantities to supply the U.S. energy deficit range from 7.2 million bbl/day in 1975 to 19.2 million bbl/day in 1985 (Table 1).(2) Transport of this oil will be by tanker ships into coastal ports. The development of supertankers [~250,000 dead weight tons (DWT)] and offshore deepwater ports for their operation will occur in this period. Transshipment of oil to land in smaller tankers (~50,000 DWT) from these ports is a possibility. Estimates of traffic density increases in U.S. ports (with and without deepwater ports) range from about 15,000 tanker trips/year in 1975 to a near maximum of 25,000 in 1980.(3) Using methodology developed by the Coast Guard(4) estimates of annual incremental oil spill volumes as a function of oil import level have been made. These are given in Table 2 for three levels of daily oil imports. Using the worst case data of Tables 1 and 2, it can be shown that approximately 800,000 bbl of oil would potentially be spilled in U.S. coastal and harbor zones within the next 10-year period (1973-1983) due to increased oil imports in the absence of superports. Insofar that superports come into existence within this period, the amount would be expected to decrease, unless all of the oil is transshipped from offshore superports in tankers rather than by pipeline. The Coast Guard methodology used is based on statistical analysis of 10 years of past accidental spill incident history (1960-1970) as a function of spill volume. In addition to spills

TABLE 1. RANGE OF OIL IMPORTS (Million bbl/day)

Case*	1970	1975	1980	1985
Best	3.4	7.2	5.8	3.6
Worst	3.4	9.7	16.4	19.2

* Best case: Results from maximum effort to develop domestic fuel sources.

Worst case: Results from continuation of present trends in U.S. oil and gas drilling, i.e., continued deterioration of U.S. energy supply posture.

TABLE 2. ANNUAL SPILL VOLUMES AT VARIOUS OIL IMPORT LEVELS (barrels)

Import Level (million bbl/day)	Case I No Superports	Case II Superports*
3	15,900	3,400
6	32,600	6,500
9	49,400	10,000
Average number of bbl spilled per million bbl/day imported	5,400	1,100

* With transshipment by pipeline.

due to accidents, operational spills due to leakages, poor housekeeping, intentional dumping, etc., can be expected to increase. In 1971, these amounted to nearly 9 million gallons in U.S. coastal and inland waterways.

Geophysical Modification of the Earth

Problem. In attempting to supply a growing demand for both renewable and nonrenewable natural resources, man resorts to a variety of technological measures which often have serious and widescale effects on the environment. Examples include (1) the use of underground nuclear explosions to release natural gas supplies, (2) strip mining for coal and mineral ores, (3) dredging to create deepwater ports for oil-bearing supertankers, (4) stream channel modifications, (5) ocean floor mining, (6) pipeline construction, (7) silviculture practices, (8) deforestation, and (9) the construction of dams for flood control, irrigation, and power production. In each case, major physical disturbances of the earth are made frequently over large land areas. These disturbances often cause such immediate and long lasting ecological and sometimes irreparable effects as: mine drainage, erosion, release of toxic substances, unsightly and nonproductive terrain, species erradication, etc. It is illogical to suggest that such practices be abandoned, since so long as man seeks to upgrade his standard of living, the demand for materials and energy will continue. The problem is to find ways of providing these needs while at the same time minimizing the impact of the technological activity involved.

Magnitude. Within the constraints of this study only two near term problems were examined in any detail. These were coal mining and stream channel modification.

In a recent study for EPA(5) Battelle estimated the volume of acid mine drainage produced in 1970 from bituminous coal mines of the Appalachian mining region as 103.8 billion gallons. In that year, 294 million tons of bituminous coal were mined in the region. National Petroleum Council predictions for coal demand indicate an increase of 70-100 percent in demand (worst and best case) for coal by 1983. Assuming mining of bituminous coal in the Appalachian regions grows accordingly, the amount of acid mine drainage there would nearly double to 200 billion gallons in 10 years if no preventative measures are taken. Another source has estimated 500 billion gallons of mine drainage in the Appalachian region, containing 5-10 million tons of acid and polluting over 10,000 miles of surface streams and 15,000 acres of impoundments.(6) When extended to all of the U.S. and expanded to include strip mining as well, the amount of acid mine drainage from these sources is enormous indeed.

A recently issued study(7) prepared for the Council on Environmental Quality analyzes the dimensions of environmental effects from channel modifications underway and planned by the Corp of Engineers and the Soil Conservation Service. This is another activity where the areas affected are large and the potential environmental effects are of profound interest. The length of watercourses channeled by these two agencies by 1972 amounted to about 11,180 miles. By 1980, if projects started and planned are accomplished, this will increase to 35,000 miles. Thus, a study of the type conducted is timely with respect to the land area to be affected in the near future.

The projects undertaken were for flood abatement, drainage of wet land, erosion control associated with channelization programs, and in rare instances, related to water supply, water quality, or recreation needs.

The conclusions appear to be that while the purposes desired in initiating a channeling project are generally achieved, there are potential impacts which have far reaching implications on the ecology of the affected, surrounding and downstream areas. Some of these include

(1) Reduction in wildlife habitats and food resources through hardwood elimination
(2) Stream water quality impairment from water table lowering
(3) Reduction in aquatic organism productivity and diversity of aquatic life
(4) Increased erosion (among most severe effect) and sedimentation affecting turbidity, light penetration, algal productivity and hence fragile food webs
(5) Enhanced downstream flooding.

Analysis of the benefits which offset these effects is complex as both direct and indirect social, environmental, and economic values and costs must be considered. In this particular setting, benefits were found to outweigh the cost of such projects.

Trace Elements (Metal) Contaminants

Problem. Toxic trace element contaminants (principally heavy metals), as a class, have already been implicated as a particular segment of concern in the spectrum of identified environmental pollutants. For example, beryllium and mercury have been officially declared hazardous air pollutants and national emission standards established. Cadmium is on a proposed list. Others such as selenium, vanadium, manganese, lead, etc., are under study.

The pathways by which trace element contaminants are distributed to man are complex and encompass essentially all media and their associated ecosystems. As with many pollutants where effects are manifest at low concentration levels, control is difficult to exercise once the metals are well dispersed along a pathway. The biological conversion to even more toxic forms, e.g., organometallics, and accumulation in ecosystems further complicate the problem. Interruption of such pathways at key points through the application of control technology is a current major U.S. effort. The sheer magnitude of the pathways and sources, however, combined with a lack of information on the human health and biosphere effects of trace contaminant deficiencies and overabundance, underscores the future importance of this pollution problem.

Magnitude. Trace elements, particularly the heavy metals, disperse into the environment from a variety of sources. Major sources include: (1) natural sources; (2) wastewater from metallurgical processing operations--60 billion gallons in 1970-1971 from the lead-zinc-copper industry alone and containing 0.01 to 25 mg/l of specific contaminants(8); (3) particulates to the air associated with commercial-production consumption activities--about 500,000 tons/year can be projected (Table 3) for 1983 for a selected 15

TABLE 3. PROJECTED AIR EMISSIONS OF SELECTED ELEMENTS

	Tons of Pollutant		
Element	Base Year*	1978	1983
Zn	151,000	216,700	273,000
Mn	19,000	25,840	31,720
V	18,000	37,240	58,370
Cu	13,500	20,680	24,070
Cr	12,000	14,980	17,800
Ba	10,800	17,290	22,860
B	9,500	14,000	17,690
Pb**	9,300	11,840	14,370
As	9,000	12,750	16,990
Ni	6,000	10,940	17,500
Cd	3,000	4,090	5,050
Se	900	1,240	1,560
Hg	800	1,160	1,560
Sb	350	460	550
Be	150	200	260
Totals	263,300	389,410	503,350

* Data for 1968-1971 period.(9)

** Excludes automotive sources.

elements assuming no reductions in pollution due to process changes or added levels of pollution control over the 1968-1971 period; (4) contaminated sludges and solid residues to land disposal from mining, beneficiation, and resource extraction technologies--an estimated 3 billion tons/year in the 1978-1980 period*; and (5) trace-metal contamination from automobile exhaust, disposal of municipal sludges, and area applications of agricultural chemicals.

Sources, pathways, and health and ecosystem effects especially need further study in order to establish controls that have acceptable economic and social tradeoffs between man's need for material resources and environmental health.

Hazardous and Toxic Chemicals

Problem. Public attention has been focused often in recent years on newly identified hazardous chemicals or classes thereof: diethylstilbestrol, thalidomide, DDT, polychlorinated biphenyls, pesticides, phthalic acid esters. What has been startling is that, before a warning had issued, the environmental hazard had become so widespread as to seemingly preclude any immediate or short-term remedy. Today's chemicals, initially synthesized to meet the technical requirements of a new product, frequently become widely proliferated among hundreds of products of unrelated uses. Thus, PCB's showed up in paints, carbonless carbon paper, electrical transformers, coolants, etc. The manufacture, distribution, consumption, and disposal of such products introduce the associated chemicals into the environment along a variety of incredibly complex pathways, many of which impact directly or indirectly on man. E.g., in a study of street contaminants and their contribution to urban storm water discharges(10), PCB's and seven pesticides were identified as significant components.

Of all the chemical classes now in use, pesticides appear to pose the most difficult pollution problem in the near future. Pesticides, synthesized and applied for their lethality toward pests, are spread over literally hundreds of millions of acres of the U.S. Many are resistant to biodegradation, toxic to man, and accumulate in plants and animals. The effective control of this class of chemicals is fraught with social and political consequences.

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* See description of these in later problem discussions on waste sludges, liquids, and solid residues.

Magnitude. A recent study has analyzed in detail the manufacture of pesticides in the U.S., using a broad definition of the term, viz., including rodenticides, insecticides, larvacides, miticides, mollusicides, nematocides, repellents, synergists, fumigants, fungicides, aligicides, herbicides, defoliants, dessicants, plant growth stimulators, and sterilants.(11) 1971 production quantities were determined to be over 1.3 billion pounds. About 275 specific pesticides are of current commercial importance and perhaps as many as 8000 individually formulated products are marketed for end use applications. Projected 1975 quantities are only slightly higher than 1971, perhaps reflecting the current environmental concern and legislation. There is little reason to believe 1978 will be greatly different.

Crop dusting as a method of application is a big business. In 1972 agricultural crop-dusting aviators flew about 1.6 million hours, up 11 percent from 1971, covering a record 120 million acres.(12) Justification for this method includes factors like: faster application--one airman can cover 100 acres in an hour compared to a day for a ground rig; heavy rains sometimes keep tractors out of fields; one-twentieth less fuel is used in air application; soil compaction which hurts crops is avoided. Unfortunately, this method has environmental hazards: some error with respect to placement of the chemical is likely; drift of pesticides to adjacent fields is troublesome; wildlife in the area can be affected; and the question of human effects is always present.

In addition, pesticide usage in urban areas has grown rapidly. The variety of product formulations available for application by the home owner is large. Aerosol containers for this purpose alone amounted to 100 million units in 1970.(11) Presumably, such uses contribute to the pesticide concentrations observed in street solids from eight major cities in the U.S. which were on the order of 0.00125 lb/curb mile (including PCB which was of higher concentration and the major constituent in most cases).(10)

The specific pesticides identified were the more persistent ones such as the chlorinated hydrocarbons (p,p-DDD, p,p-DDT, and dieldrin) and organic phosphates (methyl parathion).

In addition, major spills from highway, rail, and river transport vehicles have occurred wherein pesticides were involved. Fish kill data from such spills are available which illustrate the geographically widespread nature of the problem.(13)

It is concluded that the new methods of identifying hazardous substances before they are widely proliferated in commercial use categories are needed, along with criteria for establishing priorities for testing and research.

Emissions from Automotive Fuels, Additives, and Control Devices

Problem. The automobile as a major source of air pollutants is currently receiving national attention. Strict standards have been legislated on automotive exhaust emissions and these are leading to significant technological developments ranging over new engine design and modifications, development of catalytic convertors for exhaust treatment, formulation of new fuels and additives to reduce levels of legislated emission components. The adoption of certain of these technological alternatives has already occurred and others will be introduced within the next 2 to 10 years. The number of automobiles involved, their relationship to major population centers, and the complexity of the impacts that result from each technological alternative suggests a need for careful evaluation before-the-fact of the consequences which are likely to occur. Some indicators of potential problems already exist.

Magnitude. Since 1960, new automobile purchases as a percentage of registered vehicles have been at a rate of 9 to 11 percent a year. These purchases have exceeded replacements by 2 to 4 percent per year, indicating a significant growth in the number of autos on U.S. roads. At the present rate, by the year 2000 the number of autos will about equal the number of people in the U.S. (~250 million).

Gasoline consumption has on the average risen steadily for automobiles since cars became available. The rate of rise has been sharper since about 1968. Total gasoline consumption by cars in the U.S. is projected to be 25 percent higher in 1980 than in 1972, a fact attributable both to a greater number of cars (and hence road mileage) and to increased gasoline consumption per car.

The contribution of auto exhaust to smog in large cities has been experimentally verified and, in fact, was apparent as early as the late 1950's in the U.S. Public reaction to this problem led to the enactment of emission standards for hydrocarbons and carbon monoxide beginning in 1968 and nitrogen oxides beginning in 1972. These standards in turn have resulted in the rapid development of catalytic control devices and other approaches for use in meeting the standards.

There are some 300 fuel additives in use for highway vehicles and the expectation is that the number will increase significantly in the near future. Removal of lead from gasoline, since it interferes with effective operation of planned catalytic control devices, requires reformulation of the gasoline to compensate for the resulting octane rating and antiknock property reductions. Inorganic additives being considered include manganese, boron, nickel, and phosphorus. Changes in the organic makeup of gasoline involve increases in branched chain alkanes, olefins, or aromatics. Increases in aromatics appear to be the simpler approach, but if this course is followed an increase in emitted polynuclear aromatic hydrocarbons (PNA) can be expected.

Current catalytic convertor designs (platinum and noble metal catalysts) remove between 50 to 70 percent of the PNA. The remainder would contribute to exhaust emissions. It has also been suggested that the partial oxidation of PNA by the catalysts may actually form a more toxic carcinogen than PNA itself.(14) Phenol emissions would also increase from the added aromatic components. It, too, has carcinogenic activity, especially with respect to skin and the lungs. Other reported increased emissions would be benzene, aromatic aldehydes, and nitrogen oxides.

The incorporation of catalysts as a means of meeting standards is planned by most American and foreign automobile manufacturers. As with most pollution-control equipment, there is a potential disposal or recycle problem and perhaps emissions associated with the devices themselves. With EPA's required durability of 25,000 miles for each catalytic convertor and an assumed annual travel of 10,000 miles per automobile, the need for large-scale continuous disposal or recycle of catalytic convertors will be reflected 2-3 years after their installation, i.e., 1977-1980. An estimate is that by 1985 nearly 120,000,000 lbs per year of spent catalyst will require treatment or disposal.

Emission of very fine metal-containing particles has recently been observed during the operation of a vehicle.(15) This would represent a new contribution of fine particles to air pollution.

This problem is going to develop within the next 5 years as control approaches are applied to over 10,000,000 new cars/year in compliance with existing Federal statutes.

Disposal of Waste Sludges, Liquids, and Solid Residues

Problem. Future problems related to the disposal of waste sludges, liquids, and solid residues are a direct result of the relatively recent passage of environmental legislation aimed at cleaning up the air, water, and land environment. Two aspects are apparent: first, with the addition of pollution control devices to air and water emission points of industrial, utility, and municipal processes, large volumes of liquid and solid residues are or will be generated. Much of the material collected has some potential value, although it may be some time before technology for recovery of the values will become available with current institutional, economic, and political constraints. Examples of these residues current and foreseen include sulfate sludges from power plant SO_x scrubbing, sludges from increased application of secondary treatment to municipal wastewater treatment plants, inorganic dusts from add-on particulate control devices required by industry and utilities (fly ash, e.g.), and ultimate residues remaining from the processing of industrial solid (frequently hazardous) wastes by contract waste disposal firms. Second, large quantities of industrial, municipal, and utility residues that were generated and routinely disposed of before the advent of environmental quality control efforts have come under scrutiny with respect to their potential for polluting (trace metals, BOD, toxicity, etc.) various media. Past practices of dumping into watercourses, lagooning (near watercourses), burial in uncontrolled landfills, etc., can no longer be employed. Affected are sludges from drinking water treatment, dredgings, coal production residues, and slimes from metallurgical and inorganic chemical production.

Because of these and other factors, the search for suitable ultimate disposal routes has become a major preoccupation of the generators of these wastes. However, the options for such disposal have diminished.

Magnitude. The magnitude of this problem is best illustrated by reference to a limited number of specific waste items within the two categories of (1) new bulk residues directly resulting from recent pollution control legislation and (2) residues from continuing past practices which present acute disposal problems as a result of new environmental concerns.

Pollution control residues include these items:(1)

(1) Sludges from throwaway processes developed for SO_x removal from combustion flue gas--48 million T/yr by 1980

(2) Increased sludges and brines from the adoption of secondary and tertiary treatment of sewage by municipalities--11 million T/yr (dry solids) by 1980 for secondary treatment sludges alone

(3) Flyash from increased coal consumption by utilities--26 million T/yr by 1978

(4) Residues from treatment of hazardous military, industrial, and nuclear power plant wastes--3 million T/yr by 1978-1980.

Other high volume residues historically a disposal problem will increase in proportion to material needs of man. Examples are:

(1) Sludges from drinking water treatment--0.5 million T/yr

(2) Mineral ore tailings from coal, copper, phosphate rock, iron ore, lead-zinc, alumina, nickel, etc., extractions--2-3 billion T/yr by 1980

(3) Dredging spoils from major port construction, stream channel alteration, and pipeline development activities.

Controlled land disposal, as an acceptable alternative, requires more study if the needs of the next decade are to be met.

Critical Radiation Problems

Problem. Exposure of man to radiation sources which are not of a natural origin is increasing. The growth of nuclear power and electronic technology raises this issue as one which will have an impact within the 5-10 year period.

Radioactive releases from nuclear materials required for military and peaceful uses have been widely recognized as a serious problem. International nuclear test bans have been formulated to deal with the former. Releases associated with nuclear power generation, while significant, have received much study - to the extent that these sources, quantities, and effects have been projected and assessed before-the-fact.

Less well studied are the radiation sources associated with accelerating use of a whole spectrum of consumer, medical, industrial, military, and commercial devices and systems based on electronic technology. Near term increases in the numbers of devices in use and in the power output levels suggest a need to further evaluate the problem. Thermal effects are largely known. The extent of nonthermal biological effects is largely unknown.

This report focuses on electromagnetic radiation in the radio-frequency range as an area within the general problem statement where information is needed to keep pace with future technology trends.

Magnitude. There is a constantly increasing number of electromagnetic sources in this country in the radio-frequency range. [Radio frequency (RF) is defined very broadly as extending from the extremely low frequencies through the microwave range, i.e., from less than 10^2 to 10^{10} Hz.] With increasing numbers of sources there are also increasing power outputs per source at many frequencies from the proposed Navy Sanguine Communication antenna at less than 100 Hz to radars at 10^{10} Hz.

In general RF radiation is used by man in four ways: (a) as a heating source, (b) as a detection method (radar), (c) as a communication method, and (d) as a power transmission method. The relative importance of the hazards from RF radiation sources used in these ways is probably in the order listed.

Residential microwave ovens are probably the current most important potential hazard source for the general population. This is true because of the total number in use now and projected in the future. They are becoming more popular as a food heating source each year. Table 4(16) gives the number of units in use from before 1967 to the present and the projected sales for the next 4 years. Although the power level of residential microwave ovens is in general 600-800 W, much lower than industrial units, there is a potential for 20,000 to 100,000 people being affected by just a few percent of defective units among the present ~1/2 million installations. This is projected to increase more than 10 to 1 in the next 5 years. The commercial microwave oven market, industrial microwave processing units, and medical diathermy equipment are other sources of exposure.

Radar and other detection devices employing RF radiation constitute a health hazard only under special circumstances (except for possible low level effects). Radiation levels found in the vicinity of high-powered broadcasting stations in most practical instances are considerably lower than those usually associated with biologically hazardous fields. However, close to high-powered broadcasting antennas it is possible to atttain field strengths approaching the safe minimum.

The growth of radio broadcast stations appears to be nearly linear. Table 5 shows the number of TV and radio broadcast stations in the U.S.(17)

Power transmission, based on solar energy sources, while theoretically feasible, will not become a factor in the next 5-10 years.

TABLE 4. RESIDENTIAL MICROWAVE OVEN INSTALLATIONS

	Retail Sales	Home Installation
pre-1967	10,000	10,000
1967	5,000	15,000
1969	30,000	65,000
1971	120,000	235,000
1973	375,000*	860,000
1975	840,000*	2,260,000
1977	1,750,000*	5,260,000

* These estimates considered to be conservative.

TABLE 5. TOTAL BROADCAST STATIONS IN U.S.

Year	TV	Radio
1945	6	930
1950	97	2832
1958	421	3310
1960	562	4256
1965	674	5537
1971	892	6976

It is evident from the present knowledge of the RF radiation environment, that there are specific hazards that present current dangers. With safety devices and education no widespread danger to the public will occur in the next 5 years. Low level effects should, however, be investigated to remove the uncertainties expressed by some persons and agencies.

Fine Particulates

Problem. Chemically active and inert fine particulates emitted to the air constitute a potentially serious health hazard due to their retentivity in the human respiratory tract. This problem ranks high in terms of (a) direct health effects on man, (b) multiplicity of sources, (c) the relative persistence and pervasiveness of fine particulates once they are emitted, and (d) the difficulty of control before, and mitigation after, emission. Even with the best available control technology, which will result in a significant reduction in total particulate emissions, a major fine particle fraction will be emitted. The health hazard can be quite out of proportion to the mass involved, whether the particulates are chemically active or inert.

Magnitude. Fine particulate matter is defined as a material that exists as solid or liquid in the size range of 0.01 to 2 microns in diameter.(18) The lower size limit of 0.01 micron is based upon considerations of potential adverse effects of particulates on human health. The upper limit is based upon the fact that the collection efficiency of present control equipment deteriorates significantly below 2 micron particle size.

A comprehensive review and assessment of various environmental effects have been documented in an EPA report entitled "Air Quality Criteria for Particulate Matter".(19) The environmental effects described included: (1) effects on health, (2) effects on visibility, (3) effects on climate near the ground, (4) effects on vegetation, (5) effects on materials, (6) effects on public concern, (7) suspended particulates as a source of odor, and (8) economic effects. The first two are probably among the most serious effects.

Projections of fine particulate emissions by quantities and sources have been made for the years 1975 and 1980.(18) Two methods of projections were used. Method I assumed that there will be no change in the net control for each source, which would result in increases in emissions in proportion to increases in production capacity. Method II assumed that all sources will be controlled by 1980, and that increased utilization of the most efficient control devices will continuously increase the efficiency of control for fine particulates so that by the year 2000 the control efficiency will reach the efficiency of baghouse control, which is the best currently available method for fine particulates.

The projections indicate that the fine particulate emissions from industrial sources through 1980 will remain at a significant level (better than 3 million T/yr) even after the application of control to all such sources.

A substantial portion of fine particulate emissions originates from nonindustrial sources for which no practical control method is available. These sources include mobile sources, such as automobile exhausts and tire wear, forest fires, cigarette smoke, ocean salt spray, and aerosol from spray cans. The emissions from these sources will continue to remain substantially at the existing levels through 1980. The fine particulate emission from these sources, excluding forest fire, in 1968 was estimated at 2.46×10^6 tons/yr.(19)

Expanded Drinking Water Contamination

Problem. Drinking water for human needs is derived from the same sources that supply water needs for human enterprises - industry, power production, irrigation, and the like. These sources unfortunately are also the receptors of pollutants from the same enterprises. Current USPHS drinking water standards (1962) provide impurity limits for only a relatively few pollutants under the classifications of bacteriological, physical, chemical, and radioactive characteristics. Water meeting these standards is generally accepted by the public as safe.

Several events of the past decade have raised new concerns about the relative safety of drinking water. One is that methods of detecting constituents in water have become more sophisticated permitting even lower concentrations of contaminants to be recognizable. Another is the increasing awareness of the extent to which the environment is polluted, i.e., new recognition of the sources, amounts, pathways, and effects of specific pollutants. Coupled with the latter is the realization that the numbers of chemical entities synthesized, produced, and utilized in the U.S. have been increasing dramatically. Since these substances in most cases eventually find their way into water supplies, a reexamination of drinking water safety appears to be a necessity. The problem is intimately tied to problems of trace metals, pesticides, fine particulates, and longer term health effects of these.

Magnitude. Table 6 shows the situation in the U.S. with respect to municipal water supply. A projected increase between 1960 and 1980 of from 20 to 33.5 billion gallons per day will serve domestic, public, commercial, and industrial segments comprising municipal users. Municipal users in turn represent about 8 percent of water usage for all purposes in the U.S. Per capita water usage of municipal water has not changed drastically since about 1955 and is in the range of 150-160 gallons per capita per day.

The percentage of the U.S. population served by municipal water supply systems has increased over the same time period as follows.(23)

1960	75.2
1970	82.2
1980	90.7

This suggests two environmental factors: (1) there is still a significant population fraction relying on untreated sources (wells, e.g.) which may or may not have been exposed to the extensive range of pollutants known to be released each year from production-consumption activities; and, (2) the volumes of sludge from water treatment which require disposal (and which in themselves constitute a disposal problem) will continue to rise through 1980. This quantity is in excess of one billion pounds a

TABLE 6. MUNICIPAL WATER SUPPLY IN THE U.S. (1960-1980)(20,21,22)

(Billion gallons per day)

Year	Domestic*	Public*	Commercial*	Industrial*	Total Municipal
1960	8.6	3.0	3.8	4.6	20
1965	10.2	3.6	4.5	5.4	23.7
1980	14.4	5.0	6.4	7.7	33.5

* Based on estimated 43, 15, 19, and 23 percent of total municipal use respectively for domestic, public, commercial, and industrial.

year at present. Disposal of the latter into streams is no longer considered acceptable practice.

The number of different types of contaminants in water sources from which drinking water is derived is large. The awareness of just how large has been developing in the past decade as a consequence of (1) studies of sources and pathways to the environment of emissions to the air, water, and land from all of man's activities and natural phenomena (weathering of earth's crust, volcanoes, lightning-induced forest fires, etc.) and (2) increasingly more sophisticated detection instrumentation. The types of contaminants include organics, inorganics, biologicals, radioactive elements, low taste and odor threshold compounds.

One of the primary needs associated with the control of drinking water contaminants is the establishment of the levels at which given substances will be acceptable in water. The expenditures of large sums of money to bring contaminants to levels that have no scientific basis would not be wise. The possiblity of direct large-scale reuse of treated municipal wastewaters for drinking purposes, while still far in the future, requires that a study of acceptable levels based on health effects data be started now.

Irrigation (Impoundment) Practices

Problem. With the current and projected population levels in the U.S. and abroad, the most productive utilization of agricultural land is essential to meet rising food demand. Irrigation of arid and semi-arid regions of the U.S., to meet agricultural and land development needs, has grown ten-fold in the past 70-75 years.

Environmental impacts from irrigation accrue from the salt concentration which naturally occurs as the pure water is extracted by plants and evaporates to the air. Return of these saline waters to a receiving stream or underground water supply provides a detrimental effect. Other impacts result from the construction and operation of impoundments to provide irrigation waters.

The sheer magnitude of this problem in terms of (1) acreage and water quantities affected, (2) growth in the practice, and (3) complexity of the impacts raises this as a future problem of national importance.

Magnitude. The application of irrigation practices to arid lands has tended to rise at a steady rate since 1940. The land area being irrigated has increased 100 percent from 1944 to 1970 and is forecasted to increase about the same rate to 1980 when 45 million acres will be under irrigation.(24) Even though the percentage of water utilized for irrigation has dropped from a high of 52 percent of the total water usage in the U.S. in 1940 to a predicted low of 37 percent in 1975, the absolute magnitude of water needed for this purpose has more than doubled in the same period. Irrigation as a practice appears to have been increasing at the rate of 2.3 billion gallons a day per year since 1960.

The effects of irrigation are widespread and complex. Salinity increases irrigation water, supply reservoirs and downstream river waters constitute the most prominent stressor. Added to salinity are other toxic substances like heavy metals, pathogens, radioactivity, and pesticides carried from the irrigated land with the return flow waters.

Reduction in river flow downstream from the supply impoundment results in an adversely altered water environment, i.e., higher water temperatures decreses dissolved oxygen and hence reduces assimilative capacity of the water, and other parameters.

Even more profound effects covering large areas can result to downstream estuarine environments. In the 1960s, Copeland(25) reported on the effects of reduced freshwater flow in the fishing industry in south Texas. A 50 percent reduction in commercial fishing occurred at Aransas and Corpus Christi Bays. Copeland and Hoese(26) also noted the destruction of one of the largest oyster producing industries in the world due to the reduced freshwater inflow into Galveston Bay. It was postulated that increased salinities which in turn triggered increased temperature fluctuations initiated the loss.

CONCLUSIONS

Significant national problems of the near-term future are identifiable using the simple screening and ranking framework employed in this study. A similar aporoach should be useful for identifying problems of a regional nature. While the program time frame and budget did not permit extensive (1) exploration for problems beyond EPA or Battelle sources, (2) development of new ranking methodologies, (3) exploration of all the social, political, and technological implications of the problems identified, or (4) examination of control possibilities, it is felt that results justify continuation of efforts of this type as a need essential to EPA's mission. A continuing exploration of the implications of legislated pollution control measures, increased industrial production-consumption activities, and the introduction of new products and processes appears necessary to avoid the costly consequences of late application of control measures.

ACKNOWLEDGMENTS

This work was supported by EPA's Implementation Research Division under Contract No. 68-01-1837.

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SESSION IX

ENVIRONMENTAL MONITORING REQUIREMENTS

CHAIRMAN

MR. C. E. JAMES

OFFICE OF MONITORING SYSTEMS, OR&D

SENSOR UTILIZATION IN NEW ENGLAND

by
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Remote sensing can be of considerable assistance and benefit in its application to environmental problems in New England. The New England region is one of contrasts, ranging from congested urban-industrial complexes in the south, developed and undeveloped coastal areas along the eastern side, to isolated industrial pockets set in rural areas dominated by thick forests in the north. Remote sensing would permit an overview of all these areas so that not only the present status of an area would be known, but any changes, either ameliorating or deteriorating, would become quickly apparent. The documentation of existing and changing conditions in our region would allow more judicious issuance of permits to industries and municipalities and also would aid in more judicious use of land. More immediately, the Surveillance and Analysis Division can utilize the advantages offered by the field of remote sensing not only to augment its monitoring activity but to decrease the amount of sample analyses necessary for monitoring purposes.

Uses of remote sensing in Region I are outlined below:

Monitoring Requirements

A. Industrial - thermal plumes of power plants
    effluents into rivers, lakes, tidal areas
    air emission surrounding industrial areas

B. Municipal - effluents from treatment plants
    runoff from urbanized areas
    rural community development

C. Combined and Miscellaneous effects
    eutrophication in lakes and estuaries
    heat island build-up from industrial-urban complexes
    mining and ocean dumping operations

Future Applications

A. Land Use Planning

B. Coastal Zone Management

C. Crop Disease Detection

Monitoring Requirements

A. Industrial

For more definitive documentation of extent of thermal plumes from power plants, we would like aerial overflights made of all 49 major power plants already in operation, using infrared with resolution down to 1°C isotherms. The survey should be made frequently during the summer and winter months. Power plants located in tidal areas should have overflights made at slack high and low tides. Data obtained from *in situ* monitoring in the thermal plumes would allow correlation between the infrared surveys and the ground monitoring. Modeling studies applied to the plume would allow the extrapolation of the surveys below the surface waters. We would be able to determine more precisely the extent of the thermal plume in correlation with the number of generating units which are operational at the time. The survey would also allow us to estimate the heat sink resulting from one or more plants discharging heated water into a body of water.

Effluents from single and combined industrial sources should be monitored to determine amount and nature of wastes which are being disgourged into the atmosphere and into the hydrosphere, particularly if it is possible to detect and analyze for different waste products by remote sensing methods. The overflights should be made at irregular but frequent intervals.

Pulp and paper mills are located throughout the northern and central New England region. Defining quantity and aerial extent of the effluent at the present time would help in issuance of permits to these industries. Also, sludge blankets resulting from mill activities have formed in rivers and lakes adjacent to the mills. If it is possible, we would like to assess the aerial expanse, depth and composition of this sludge in order to have a better idea of the extent of the water bodies that are affected by the mill.

Petroleum terminals and storage areas have been a source of considerable oil spillage and seepage, both on land and onto water bodies. Detection by remote sensing of leaking storage tanks or their piping systems would allow EPA to obtain immediate corrective measures from the appropriate industry both because of the pollution and the safety hazard. Also at petroleum terminals along the seacoast, considerable spillage of oil takes place during the transfer of the oil from tanker to the storage tanks. Only the more serious spillages come to our attention. With overflight scans, we could document all spillages and ask that corrective measures be taken. With frequent aerial survey, off-shore "mystery spills" can quickly be identified as to origin.

If the technology of remote sensing has been developed to the level where metals can be detected in water effluents, we would want effluents from metal plating industries monitored in our region. For instance, one company in Massachussets produces printed circuit boards, thin film devices and various metal plated parts and accessories for communication systems. Their industrial wastes are combined with their sanitary wastes for treatment before being discharged into a river. We would like to distinguish between the metal and sewage wastes through remote sensing, thereby assessing the contributing quantity of effluent from each source.

Particulate emissions into the atmosphere are being monitored routinely in industrial areas of New England. Additional simple, reliable equipment with accepted methodology needs to be developed for routine type sampling. This additional data coupled with the data that already exists and infrared and meterological aerial surveys would not only document the extent of the aerial pollution but also the total area impacted by these emissions meteorologically as well. If the technology exists to trace the six common air contaminants individually, plume configuration could be characterized for each, and with the routine monitoring data, modelling techniques could be verified or adjusted for correction. If none of the six air contaminants can be distinguished from IR or other surveys, perhaps a benign tracer visible to IR scanning could be combined in stacks with a specific contaminant for quantitiative fingerprinting.

B. Municipal

Granting of municipal permits to sewage treatment plants is of prime immediacy. It would be helpful during this period if surveys could be made to determine quantity, composition and detectable extent of the effluent from the treatment plants.

We have mainly secondary treatment plants, but some primary treatment plants still exist and a few tertiary treatment plants are coming on line. To factually document the change in effluent as secondary treatment plants convert to tertiary, and the differences between these two effluents and the effluents emanating from primary plants is of importance particularly forstate and local authorities.

Furthermore, pollution of a stream or body of water can also be caused by non-point sources. Many times a stream is already grossly polluted before it flows past the municipal treatment effluent. Monitoring of non-point sources is difficult by conventionaly methods, but with high resolution aerial surveys, better information is possible of the contribution of pollution by non-point sources. As corrective measures are taken, the results would be documented in subsequent aerial surveys.

Storm water runoff from urbanized areas creates sudden high sediment loads and great volumes of water entering water bodies. How does this increased load effect changes in river channels? Determining the contribution of load and its effect from urbanization versus that due to agricultural activity, would allow for better remedial action either by the EPA in the urban areas or other agencies in the agricultural areas. Overflights before and immediately after storms would help in this determination.

In rural areas, septic tanks are the dominant method of household waste disposal. Many of the septic tanks are located in unsuitable soil profiles. As communities expand, particularly in recreational areas such as skiing and sea shore resorts, the ability of thin or poor soil cover to assimilate septic drainage decreases rapidly and polluted seepages result as well as contaminated ground water supplies. Overflights over expanding rural areas would allow determination of the nature and depth of the soil cover and point out where alternate methods of waste disposal should commence before the situation reaches a crisis stage.

Highways being constructed in rural areas of considerable relief may affect not only the immediate area of construction. It has up till now been difficult to document the impact of road construction on an entire watershed even though this has been suggested. A detailed aerial survey before, during and several times after construction would help in proving whether there was or was not an environmental impact on the area not immediately adjacent to the construction. These surveys would help in evaluating environmental impact statements for future road construction.

C. Combined and Miscellaneous Effects

Presently a monitoring program for a eutrophication survey on 37 New England lakes is being conducted by the National Eutrophication Survey Program. This we welcome enthusiastically. We hope though, that the program in the future will include surveys of estuaries where the problem of eutrophication is also acute, particularly where the estuaries are adjacent to populated areas. Also it would be helpful if the surveys were flown during other times of the year besides summer so that we can gain information about the physical and chemical characteristics of these bodies of water.

Both infrared and ordinary photographic surveys over urban-industrial areas would show clearly to what extent heat islands are built up and how they influence the climate in the immediate and down wind areas. By comparing and contrasting the components inside and outside the heat pockets, corrective measures can be developed to lessen the heat effect. Also the scans and photographs would provide data concerning the effects of cooling towers on the local meteorology. Overflights before and after construction and operation of a power plant cooling tower which is being proposed in our region would document the heat effects of an urban area alone and then the heat effects with the addition of the cooling tower.

In Maine, New Hampshire and Vermont, there are significant mining operations. Metals and other mining products such as asbestos from the spoil heaps leach or migrate into fresh water and tidal areas. If metals and other mine products can be detected by remote sensing, the value of a survey over these areas would be immeasureable because the areas of high pollutant concentration in the aquatic environment would direct attention to the health hazard in the water and to the fishery products in these areas. Additionally, there is a potential for significant mining and drilling operations off shore. We will need aerial surveys of these areas if these mining opearations are implemented.

Granting of permits for ocean dumping is now underway. Yet detailed information of the effects of ocean dumping is not known. We would like scans made of the ocean dumping areas in our region before, during and after dumping operations to determine the total area influenced by the dumping. Also, we would want surveys made of the dump area in calm weather and after a storm, and also during different seasons, for a clearer understanding of the redistribution of the sediments during periods of high energy wave and current action. These overflights would also give us a clearer understanding of distribution of floating material from dumping and on-shore sites.

Future Applications

Aerial overflights would be invaluable in land use planning for most effective and beneficial use of the land. Soil profile,geology, topography, vegetative cover, and water resources could all be considered and evaluated comprehensively with infrared and other remote sensing methods.

Efficient coastal zone management will also profit from aerial overflights. The most appropriate activities can be planned for different areas of the coastal zone by recognizing limitations and assets as revealed by scans. One of the potentially critical coastline problems that remote sensing can explore in New England is salt water intrusion into the ground water aquifers. Drawdown of the fresh water table due to expanding resort and residential areas along the coast will result in salt water intrusion. The aerial survey would allow a multifaceted evaluation of the area for the best development of the coastal region from the standpoint of water supply, waste disposal, road access and recreational facilities.

Although not directly a problem of EPA, the control of disease and pest infestation is often directly proportional to the use of various amounts of chemical agents such as pesticides, fungicides, etc. One disease, potato blight, is well known to the farmers of New England. Frequent infrared scans in crop areas during the potato growing season can detect moisture changes in the potato plants due to fungal infection. Recognizing the onslaught of the blight well before it is visible to the eye would permit effective fungicide application when necessary and not on an intuitive basis, cutting down on the amount of fungicide distributed into the environment. Fruit blight could also be controlled in this manner. Infrared surveillance can also help determine the extent of spruce budworm and gypsy moth infestation so that only the minimum area necessary needs to be sprayed.

AERIAL MONITORING EXPERIENCE
IN REGION II

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Region II is in the formative stage of its aerial monitoring program. We are currently evaluating the several techniques available. Two missions have been flown for us, one by NERC, Las Vegas and one by NFIC, Denver. We are awaiting interpretive reports for both missions. Preliminary data indicates that IR imagery is adequate for measuring surface temperature and the size of thermal plumes. Some time ago we visited NASA, Houston to examine their archives and found much valuable information there. Contrary to our expectations we found that for our area of interest both low and high altitude missions had been flown. Unfortunately, there appears to be severe difficulty in procuring photographs from NASA.

The Houston visit caused us to reach two major conclusions: 1) even high altitude missions may be valuable for certain purposes such as land use documentation and detection of major current patterns in tidal waters and 2) if feasible, most missions should include normal or IR sensitive color photography in addition to the more commonly requested thermal IR imagery. We have found that no single technique is self-sufficient and prefer a multi-spectral approach.

We have also had considerable experience in sampling and low altitude observation and photography from helicopters. We believe that use of this technique should be strongly encouraged. As examples we cite two cases.

In a 1971 legal action against municipalities on the New Jersey shore we estimate that use of a helicopter reduced overall survey cost by at least 1/2, reduced the number of samples required by 2/3, and reduced our collection-to-report turnaround by 1/2. Observation from the helicopter allowed us to reduce the number of samples to 1/3 of the number which would have been required had we sampled by boat. On approximately 1/3 of the helicopter sampling dates boats would have been unable to operate. The helicopter operated well in 30-40 knot gusty winds. Photographs taken from the helicopter were admitted as evidence. Sampling which would normally have required 2 days by boat was performed in 3-4 hours by helicopter. Sampling manpower was reduced from 8 to 2 men. The remaining individuals were freed to work on other aspects of the survey. Sampling by helicopter allowed us to return bacterial samples to our Edison, N.J. laboratory within 2 hours of collection, well within the 4 hours delay time specified in EPA analytical methods. Since we were able to return samples directly to the lab we were not forced to deploy mobile laboratories and associated manpower.

A 1972 study in the U.S. Virgin Islands conducted by boat required a 4-man sampling crew for 15 days. Total per diem costs for the survey crew were $260/day. The 4-man laboratory analysis crew was required to stay longer because of the delay in sampling. Transportation cost was another $200/man. Because of the extreme difficulty in navigation and complexities associated with shipping samples to San Juan for analysis we were able to sample the 138 stations only twice instead of the 3 times planned. Had the survey proceeded as planned we would have been required to maintain an 8 man survey team in the Virgin Islands for 22 days. Per diem and transportation costs for this effort would have been $7200. Had a helicopter been used we could have completed the sampling in 7 days (1/3 the time) with 1/2 the manpower. Survey costs by helicopter would have been equivalent to those by boat but our lab and additional personnel would have been free for other work by 2/3 more time.

Unfortunately there seems to be no easy way to procure helicopter services, especially on short notice. Attempts to arrange services through the military have been disastrous. Major changes were required in the Virgin Islands survey because the Army National Guard reneged on an assistance agreement at the last moment. Helicopter rental is so expensive that requests for authorization from regional budgets often cannot be accommodated. We strongly recommend that Washington either procure helicopters for Regional use or establish a revolving fund for Regional use.

We regard aerial monitoring—which we would define as a combination of sampling and remote sensing—as a promising technique for the future. We see obvious uses in the NPDES permit program, thermal pollution studies, emergency response, oil spill prevention, environmental impact studies, and other activities. Apparently both qualitative and quantitative work are possible. We intend to examine the cost and feasibility of overflying heavily industrialized portions of our region for purposes of outfall detection. Aerial observation or photography could also significantly reduce preliminary reconnaissance required in advance of basin surveys and contribute better surveys by aiding sampling station selection.

We are currently developing our capabilities in the aerial monitoring area by training our personnel, examining other archives, and acquiring limited photointerpretation equipment. Unfortunately, acquisition of equipment through the property excess procedure has proved relatively fruitless. We are also encountering some difficulty in developing specifications and determining sources for PI equipment.

We recognize that aerial monitoring is a new and largely untried technique. There may even be a tendency toward oversell. Nevertheless, we feel the technique should be seriously investigated and exploited to the maximum extent feasible.

REGION III'S R&D REPRESENTATIVE REPORT

BY EDWARD H. COHEN

INTRODUCTION

Region III has the unique disadvantage of having in significant proportions almost every type of environmental problem. For example we have: 1. Acid mine drainage; 2. Oil spills; 3. Ocean dumping; 4. Municipal and industrial sludge disposal; 5. Farm runoff, both fertilizer and animal waste; 6. Oil refining; 7. Power plants, both conventional and nuclear; 8. Heavy industry air and water pollution; 9. Urban automotive emissions; 10. Urban solid waste disposal; and countless others in slightly less proportionate amounts. Pollution is generally tied to population growth and socio-economic demands for services. As environmental standards become more stringent the cost and man-power required to abate and control pollution will far out-strip this population growth curve.

In order to address these problems reasonably, the "horse and buggy" approach must be discarded by the implementation of full use of "space age" technologies. We in Region III, as I am sure in all Regions, could submit a multi-million (or billion) dollar shopping list for equipment and manpower to do the job today. However, practical considerations cannot allow such a crash program.

As an alternative plan we need:

1. Support by R&D funds and manpower for the development and utilization of "present-day" technology to solve pollution problems.

2. Continuation of "space age" advancements in pollution-sensors and continued research to satisfy our future program needs.

3. Highest priority Regional R&D needs in quality sensors must be addressed first.

REGIONAL PLANS, PROGRAMS, AND REQUIREMENTS FOR ENVIRONMENTAL QUALITY SENSORS

1. Plans

To update technology in the Region we must and are presently:

1) Maintaining current references, sources of sensing equipment, and resident expertise through the staff of Surveillance and Analysis Division, Office of Research and Development and the Library personnel.

2) Planning for the practical utilization of advanced sensing equipment for surveillance by the S&A Division.

3) And when authorized by the appropriate EPA office, use this equipment for assisting enforcement proceedings.

2. Programs

Internally Region III has encouraged further development of advanced sensors based on immediate and future needs through:

1) S&A program use, when appropriate and available.

2) R&D grant program to assist new equipment development and demonstration.

3) And through Regional priority needs in acid mine drainage, ocean dumping, oil and toxic material spills, municipal and industrial outfall.

3. Requirements

Some examples of these needs requiring rapid and inexpensive application are listed in the following program categories:

S&A Field Investigations Needs:

1) Remote air pollution source monitoring for round-the-clock surveillance. Presently, Region III's S&A Division is using low-light image intensifier equipment for visual measurements.

2) Water monitoring, especially for limited access river segments. Optical and telemeter sensors would be very valuable.

S&A Laboratory Needs:

1) Ability to rapidly analyze for those compounds within a category that are for example systemic rather than erroneously quantifying the entire category. An example might be metals in the metalic state versus a toxic compound of a particular metal.

2) Advanced automated equipment to handle larger numbers of analysis, faster and at reduced cost per work unit with retention of analytical accuracy. For example, "post-Technicon Auto-Analyzer II type" instrumentation.

3) To keep up to date in this work, Analytical Scientists should be involved, program-wise, in advanced instrument and techniques development, and up-grade continuously technical training levels by man-power development.

Air Program Needs:

1) Stationary source remote sensors (i.e., stack samplers), other than wet chemistry: i.e., spectroscopy, laser, etc. We are looking forward to the "demo" project involving a passive IR interferometer, as conceived by one of our S&A staff.

2) Mobile source and ambient portable (1 man) remote sensors, to be used in vans or aerial conveyances.

3) Integration of data from satellite and aerial remote sensing for regional enforcement use and monitoring for health effects, such as: the data from the USGS CARETS program.

4) Advanced portable sampling units that can collect and store air samples for future analysis (2-7 days later) such as in remote non-point source applications.

5) More rapid qualification of more equivalent methods developed in the past several years. In other words, let's check out the methods already done before developing new ones.

6) Methods for rapid calibration of present instrumentation.

Water Program Needs:

1) Multi-element portable analyzers, for example heavy metals detectors. Possible use of neutron activation analysis.

2) Advanced DO-TOC equipment capable of scanning layers in a river both in lateral and vertical directions, then consider BOD's.

3) Multi-parameter (quality) instrumentation for telemetric use in remote areas, such as using ERTS capabilities.

4) Water, air, biology, virus mobile labs fully equipped with auto-sensors and samplers, for emergency responses and short time field projects.

5) Remote sensing or "sniffer-type" chlorine probe for evaporation of chlorine in reservoirs that would result in health problems.

6) Deep-well remote sampling sensing probes for "in situ" water quality determination. Could also be used for leachate studies in solid waste programs.

7) By simplification of approved instrumentation presently in use technicians may release professional scientific staff for other important and more complex tasks.

8) Detection of acid mine drainage pollution, both source and non-point source by its effects on surrounding vegetation (another aerial or satellite application).

9) Thermal pollution detection to 0.5° C at various depths and planar areas by remote sensing techniques.

10) Ocean dumping sensors to identify illegal dumping, size of dump and location (in addition to remote sensors, aquatic "in situ" sensors may be of some value).

Solid Waste Program Needs:

1) Detection in sanitary land fill - leachate.

- open dump burning.
- fire detection and CO probes for underground fires in dumps.

2) Oil and Chemical spills detection by remote sensors, specifically satellite alarm systems. (Applicable also to the water media)

3) Erosion and sedimentation effects, remote sensing.

4) Remote sensing of culm dumps and refuse bank dams to detect potential damages to populated areas.

Pesticides Program Needs:

1) Detection and effects of spills on vegetation.

2) Target error and drifts detection caused by aerial or land application.

3) Detection of illegal use of defoilaging agents.

Radiation Program Needs:

1) Remote ambient detection of power plants.

2) Health effects from high radiation zones, i.e., due to mining or use of mine tailings of radioactive materials. (This is not a problem in this region but monitoring equipment would be of use)

3) Aerial monitoring equipment to detect and assist in emergency episodes of accidental leaks of radioactive materials.

Noise Program Needs:

1) Advanced equipment for surveillance when control becomes necessary by law.

2) Development of hardware from classified DoD research (i.e., submarine and infantry detection), of sensitive detectors for monitoring source of noise pollution.

SUMMARY

Although much of the instrumentation and methodology mentioned in this presentation may have been discussed during this conference, I would like to re-summarize many of the overall problems as brought forth by our regional staff.

Because the regions are limited in money, manpower, and travel, the region as well as the states we support need the National expertise to handle such aids as aerial surveillance and photo-interpretation that can only be called upon and used for stated missions. The region cannot support nor do we have a program for aerial interpretation. This of course must be backed up by extensive ground truth observations.

Portable remote sensing instruments would be very useful for monitoring suspected pollutors without wasting time and money with court orders to enter premises, causing hostilities and anxieties with confrontations, and involving other agencies (Justice) with internal problems (sensing).

The standardization of methods both reference and analytical techniques and their equivalents are a prime necessity.

Studies of how to improve monitoring efficiency, both in the field and laboratory will be very important because of time, money and manpower considerations.

Finally, continuation of the development and demonstration of aerial and satellite type equipment such as lidar, laser flurosensors and other "space age" equipment that eventually will be used by aerial, water and land monitoring systems.

RECOMMENDATIONS

1. Sophisticated, low cost, portable instruments for remote sampling, both active and passive, remote sensing and "in situ" situations that can be simplified for use by technicians.

2. Continuation of progress in ERTS-type systems and aerial remote sensing, by Inter-agency cooperation with NASA, DoD, etc.

3. More ground truth data for satellite overflights.

4. Increase in staff and money for R&D to carry out EPA approval of equivalent methods and instrumentation that will result in cost savings, speed of analysis and accuracy.

5. Increase in "in-house" capabilities of monitoring systems activities.

SECOND CONFERENCE ON ENVIRONMENTAL QUALITY SENSORS
NATIONAL ENVIRONMENTAL RESEARCH CENTER
LAS VEGAS, NEVADA
OCTOBER 10-11, 1973

Region IV Environmental Monitoring Requirements

In the Southeast Region, representing eight States with six bordering either on the Gulf of Mexico or Atlantic Ocean and the other two with numerous fresh water dammed lakes, we have a climate conducive to promoting biological activity. I do not mean to imply this as either derogatory or complementary, but rather as fact to substantiate the existence of a semi-tropical climate as well as favorable growing conditions.

Because of these circumstances, as well as the mixture of land usage in the eight States, we have many conditions that can only be adequately handled by some form of remote procedures; either photographically or electronically. This applies to the whole gamet of conditions, from eutrophication to particulates and smog, to urban development, and to both the marine and fresh water environments. Marine conditions such as "red tide," the annual "jubilee" and similar disasters, as well as fresh water fish kills, are of great concern and require considerable research before adequate solutions can be derived - the same applying to agricultural blights.

The monitoring program will have a great number of avenues for research in our environment. Areas of most pressing concern are in the requirements for control of pesticides, agricultural runoff, thermal pollution, accelerated eutrophication, disinfection, nutrients, and other related pollution. The State of Florida is experiencing a tremendous influx of people who are establishing residence in concentrated areas. This population explosion has brought about a considerable amount of dredging, destruction of estuaries, and eutrophication which continually requires verification in the form of impact statements. The adequate protection of the Everglades, Big Cypress Swamp, and the National Monument Park in Biscayne Bay can only be accomplished by continuous monitoring, and of necessity by remote sensing. Other areas of concern are the Okefenokee National Wildlife Refuse in Georgia, and strip mining for coal in Kentucky and Tennessee and iron ore in Alabama. In all of these fields, remote sensing application for monitoring the area seems to hold considerable promise.

Photography, utilizing the visual spectrum, infrared range, and possibly the ultraviolet range, may be an answer to assist these monitoring requirements. Even the indicies of light refraction could be applied to quantify the pollution problem, particularly if it were petroleum derivatives. Though there are other monitoring requirements, as outlined in memo of date 4/18/72, we believe that remote sensor development should be emphasized. In this regard, we are of the opinion that, though strongly mission oriented, our research program should become more directly associated with the developments as applied to both the EROS (Earth Resources Observation Systems) and ERTS (Earth Resources Technology Satellite) with NASA and USGS. Further development and refinement of broad spectrum band photographies, reliable remote control monitoring, and mixed media pollution evaluation would serve as starters.

Industrial pollution has always been a serious problem, whether it be air, water, solid wastes, or other. Odors, such as that from a paper mill, textile mill (rayon for instance), rendering plants, etc., are not generally toxic but they do constitute an aesthetic nuisance. Recognition of these problems, as well as noise, is now a reality; however, to quantify values by monitoring the situation is far from fact. The pulp and paper industry is big business in Georgia, and odors generated in the manufacture (sometimes detectable 30 miles distant on a humid day) is termed the "smell of money." I do not wish to state that these problems are as serious as others (such as high SO_x levels), yet they do influence attitudes where they are a persistent factor.

Another wide open area for participation is in the disinfection of water. This would involve the remote monitoring of chlorine concentrations, in both effluent and receiving water. The technology is here, everything but the transmission. Yet another area is the pesticide infestation, where the occupied region can be correctly defined and pesticide application measured accordingly.

At present, the regions do not have a good communication base with the advanced phases of our monitoring program. Though we do get some of the ERTS photographs of areas in the Southeast, we nevertheless are not currently informed of the monitoring activities performed in our region. The lack of communication between the R&D Program and other activities performed at the regional level is sometimes gross. As a consequence, any activities performed by the R&D Monitoring Program in any of the regions should be cleared with the R&D Regional Representative, as a matter of procedure. In this way, we will be kept informed so if questions are asked we can make an intelligent reply.

In closing, I would like to mention that we should consider this part of our R&D Program (Monitoring) as an eligible candidate for participation in our Technology Transfer Program. Techniques developed in our Monitoring Research will have value in application for policing the environment. Circumstances involving ocean outfalls and deep well injection require monitoring procedures that have not as yet been clearly defined.

Perhaps the most pressing problem that we in the Southeast Region have to contend with at this time is the contamination and destruction of our estuaries. This is not only accomplished by industrial expansion, but also by dredging and utilization of the spoil as landfill. We have approximately 30% of the continental coast line in our region and probably the last of much of the virgin lowland coastal areas where estuaries abound. The nutrient and salinity balance of some of these estuarine areas is now being endangered by industrial and population shifts, where fresh water is being pumped from ground water aquifers and diverted into the surface waters which flow into the coastal regions, and dredging is responsible for exterminating the marine life by siltation, stagnation and eutrophication.

Edmond P. Lomasney
Research & Development Program Director

ENVIRONMENTAL MONITORING NEEDS IN REGION V

Clifford Risley, Jr.

Presented at the Second Conference on Environmental
Quality Sensors, Las Vegas, October 10-11, 1973

In Region V we are concerned with all of the monitoring problems discussed in the past two days and if time permitted, I would like to add our comments on each issue: Air Pollution, Oil and Hazardous Materials, Land Use, etc. However, I was asked to emphasize one major area of concern and with that restriction, our major concern has to be the Great Lakes.

The five Great Lakes, their tributaries and interconnecting waterways differ greatly in quality and offer a variety of problems. Lake Superior is in general of high quality with water quality impairment limited generally to localized areas where waste discharges are introduced. The major exception to this is the Reserve Mining Co. discharge at Silver Bay, Minnesota which has had a wide spread impact on the lake.

The quality of Lake Michigan is very good in the open waters and in the Straits of Mackinac between Lake Michigan and Lake Huron. In the southern areas of the lake biomagnification of DDT and PCB's in salmon, trout and other species has prevented commercial sale of fish. Waste discharges in the Calumet area, Milwaukee and Green Bay cause severe localized impacts and concern about phosphorous, chlorides, pesticides, oil and heavy metals discharges.

Impairment of Lake Huron and Georgian Bay is generally restricted to the vicinity of waste sources, nutrient laden tributaries and embayments. These conditions are most pronounced in the Southeast corner of Georgian Bay and in Saginaw Bay where the Saginaw River has been identified as a major source of PCB's.

In Lake Erie, anoxic conditions in the hypolimnion of the central basin recurred in 1972. Low oxygen levels were also reported in the Western and Eastern basin. Lake Erie is not expected to show improvements until several years beyond the point of achieving greater reductions in nutrient and pollutant loadings.

The Niagara River which connects Lake Erie and Lake Ontario is the route whereby much of the nutrients and dissolved solids enter Lake Ontario. Water Quality impairment in Lake Ontario is mainly confined to near shore waters. Nutrient Control Programs are in progress but it will be many years before control programs are completed and improvements in water quality may be observed.

Waste discharges into the tributaries and connecting channels of the Great Lakes from municipal and industrial sources continue to impair water quality. Problems of floating oil and scum, discoloration, solids, phenols, heavy metals, and bacteria are frequent.

Acting upon these concerns the U.S. and Canada entered into The Great Lakes Water Quality Agreement which was signed by Prime Minister Trudeau and President Nixon on April 15, 1972. The agreement directs the International Joint Commission to assist the two governments in implementing the agreement and to make an annual progress report. The IJC established a Great Lakes Water Qaulity Board to assist in carrying out this responsibility.

In considering the water quality monitoring efforts of the federal, state and provincial governments in both the deep water and near shore monitoring and surveillance programs, the Board concluded that insufficient resources are committed to permit consistent and meaningful reviews of progress in achieving the water quality objectives of the agreement.

A quick summary of monitoring efforts show that each member agency has made its own individual effort. The Canadian effort has been greatest. In 1972 the CCIW made 9 cruises and sampled 1,026 stations in Lakes Ontario, Erie, Huron and Northern Lake Michigan. It also made 90 cruises in Lake Ontario to cover another 1,400 stations as part of the IFYGL (International Field Year for Great Lakes) program.

The Province of Ontario reports having sampled 200 stations in Lake Superior, 295 in Lake Huron, 420 in Lake Erie and 390 in Lake Ontario as well as some 700 samples in the connecting waterways. In contrast, three United States federal and eight state agencies reported sampling only 70 open water stations in Lake Superior, Lake Michigan and Lake Erie; a total of 33 tributary mouth stations, 75 connecting waterways, 43 water intakes, and an unidentified number of bathing beaches. In addition the U.S. effort to the IFYGL year on Lake Ontario was substantial.

Significant variations occur in the monitoring coverage, methods of sampling, analysis and reporting of data, in parameter selection frequency, spatial coverage and sample type. Among the things not being adequately assessed are the contributions from erosion and rural and agricultural runoff. We have a great need for obtaining a uniform and consistent data set for future descriptions of waste loadings and changes in water quality to facilitate comparisons and measures of progress.

When you look at the total effort in man years being applied to the Great Lakes monitoring effort by all agencies it appears to be a sizable effort, but when you consider the total manpower requirements to accomplish the goals of the International agreement it becomes staggering; perhaps beyond our most optomistic combined anticipated manpower resources for many years to come.

The best way to extend our effort and accomplish our objectives then, will be by the development of reliable sensors and automated analytical methods. These would enable us to put uniform, reproducible analytical capability in the hands of all the cooperating agencies, to put such capability on our agency vessels and perhaps on vessels of opportunity, on aircraft and at remote monitoring stations. A reliable analytical package of this type would also prove invaluable to our field surveillance crews so that they could obtain the sampling information required for intensive studies of effluents and critically affected stream segments and lake areas utilizing equipment instead of manpower.

The investment in manpower and resources by all of the cooperating agencies in the Great Lakes will continue and will increase. Using present monitoring techniques this effort will fall far short of the objectives required by the International Agreement. In order to accomplish our goals we must maximize the output of our manpower investment. It seems obvious that this could best be done by a greater utilization of remote and automated monitoring systems.

However, before we can accept and incorporate these systems we must have reliable sensors developed which can measure the parameters of concern. Until such equipment is available we must continue with our present approaches. We are encouraged by the presentations that have been made at this Conference. We applaud the efforts made to date and offer our encouragement to continue these efforts.

REMOTE MONITORING IN REGION VI

By - Ray Lozano

Remote monitoring has been utilized primarily for Surveillance and Analysis, and Hazardous Materials Control in Region VI. Applications of remote monitoring techniques have been limited to coastal zones, off-shore or rivers. No comprehensive monitoring measurement systens have been developed.

One of the earlier uses of remote monitoring was a Trinity Bay study which was a joint effort between NASA and EPA. The study was begun in the fall of 1970 as a simple test and demonstration of using remote sensing for monitoring thermal discharge into the bay. The primary objective was to verify a model that would predict thermal distribution of the bay near the discharge of cooling water from a power plant. Other earlier efforts included both color and infrared photographs of the Houston Ship Channel and Galveston Bay.

The Hazardous Materials Control Division uses remote monitoring as part of their quick response efforts. This effort to date has been mainly directed at surveillance and movement of oil spills. They hope to decrease the response time in order to use results from remote monitoring in deciding best ways for containing and cleaning up oil spills.

Among the oil spills for which remote monitoring or aerial photography has been used was a spill from a Shell drilling platform off the coast of Louisiana. Beginning in December of 1970 and continuing into 1971 the platform burned and spilled oil. The Region contracted with Texas Instruments of Dallas to take thermal infrared photographs of the spill during fly-overs.

In late September and October of 1972, 624,000 gallons of diesel oil at a San Antonio power plant was spilled. The oil went into the sub-surface and began seeping into the San Antonio River. The diesel oil in the water was invisible to the naked eye. However, by using a 35mm camera equipped with an ultraviolet filter (Wratten 39) and fake infrared film, photographs could be made of the oil. The photographs, in this case, were taken from a helicopter.

Aerial photography was also used for an oil spill in July, 1973, in the Atchafalaya River Basin. Only color photography was used in this case. Aerial photography was particularly needed in this case because the area was not accessible except by air.

Another recently completed remote monitoring survey had as its main objective the locating and providing information on discharges from waste treatment pits following a recent flood stage of the Mississippi River. This survey was conducted by NERC/Las Vegas for our Hazardous Materials Control Division. One hundred and four apparent leaks and discharges evidenced by their color, texture and shape were located and described. The area of individual leakage or mixing zone ranged from less than 500 to 158,000 square feet. This entire survey was made with color and black and white film.

Our Hazardous Materials Branch is estimating the possibility of 70 major oil spills this year and plan to use some type of remote monitoring in response to about 12 of these spills. The arrangements for these remote monitoring responses are with NERC/Las Vegas through a BOA contract.

Future applications of proposed systems look good. The imaging multispectral scanner approach for distinguishing between water pollutants, including algae and especially sediment is most applicable to Regional needs. Dredging and sediment distribution could be studied using the scanner, and a valid compliance program for dredging could be implemented.

Remote thermal mapping with infrared scanning is another technique that could be applied to potential power plant problem areas in Regional rivers. The concern here is to begin mapping now to prevent future construction of power facilities that might result in thermal blockages along any given stretch of river.

Remote sensing research appears well advanced to accomplish many operational functions required by the Regional programs. The only forseeable limitation is legal acceptance. If ground truth correlations validate the data collected to a legally and technically acceptable degree for court proceedings, then the remote systems will continue to gain Regional confidence.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION VII
1735 BALTIMORE – ROOM 249
KANSAS CITY, MISSOURI 64108

October 11, 1973

COMMENTS ON ENVIRONMENTAL MONITORING IN REGION VII AND SOME MONITORING PLANS AND NEEDS PREPARED FOR SECOND CONFERENCE ON ENVIRONMENTAL SENSORS

by

Aleck Alexander
Environmental Protection Agency, Region VII
Kansas City, Missouri

GENERAL

It seems that the word "Sensor" in the conference title is a misnomer which gives very limited and erroneous impression of the conference topics. The word sensor means to me a reactive device or element such as a thermometer, litmus paper, or pH electrode and is too restrictive in scope to include the complete measurement and recording of any one constituent and the multiple constituent monitoring procedures which this conference covers. It is suggested that the conference title be changed to more accurately reflect its broad monitoring subject matter.

Region VII (Iowa, Kansas, Missouri and Nebraska) has a variety of environmental control problems from many diverse sources which require proper controls and effective monitoring to assure protection of the environment from serious damage. The major industry in Region VII, however, is agriculture, and any adverse environmental effects of this widespread industry are difficult to monitor and control because of its magnitude and diffuse nature. Although Region VII has had its share of severe pollution incidents such as industrial spills and feedlot runoff, there are no severe chronic conditions or problems that require unusual attention or effort.

PRESENT MONITORING IN REGION

Pollution control agencies in the four states conduct routine and special air and water quality monitoring as a necessary part of their control programs. EPA monitoring supplements and assists the states in their control programs and is also used for EPA planning and enforcement purposes. In addition to ground level conventional sampling and analyses, our recent activities have included the following aerial surveillance.

1. An attempt was made to locate natural brine seeps in the Republican and Kansas River Basins using thermal infrared imagery and color infrared photos. This test was not successful presumably because of the relatively small flows of weak brine seeps involved.

2. Thermal scans of the Missouri River near Omaha and Kansas City and of several streams in Iowa showed the dispersion pattern (or plume) of cooling water from power plants into the receiving stream. The mixing patterns showed up clearly and this procedure may be used more extensively.

3. Infrared photography also was used on several reservoirs and the Big Piney River in Missouri to discern the detectability of algae and aquatic weed growths. This test was considered partially successful, but the photos have not yet been checked against field investigation results.

4. Thermal scans have been used to try to locate wastewater outfalls in the Kansas City area, but results to date have not been successful.

5. Photos made from 5,000 and 8,000 feet elevations were used to ascertain location, status, and occupancy of livestock feedlots in Nebrsaka. It was concluded that this aerial mapping was useful in locating the feedlots, but not for ascertaining their pollution potential.

MONITORING PLANS AND NEEDS

There are numerous general monitoring or specific constituent monitoring jobs that are difficult, costly, and/or presently inadequate in sensitivity or accuracy which are proper subjects for fundamental research. This includes commonplace items such as determination of dissolved oxygen in water, spill detection and identification, simple measurement of instantaneous stream flows, and characterization of the physical characteristics of various stream sections.

Region VII is using aerial evaluation of feedlot operations to ascertain conformance of open and partially covered feedlots with conditions of the NPDES permits. Observation flights supplemented by 35mm photos are made in a high-wing aircraft at 500-2,000 foot altitudes (AGL) to determine lot size, drainage characteristics, livestock load, feedlot wastewater retention pond conditions, and other factors. It is estimated that a 50-75% reduction in cost and manpower will result over conventional ground level surveillance. Flying time to cover 7,500 feedlots in the four states in Region VII is estimated as 150 days. Following significant rainfall, routine spot checks to determine serious problem areas also may be made by flights and selected photos of feedlots and ponds. It appears that the total aerial surveillance work potential in Region VII may make full-time use of one airplane.

Region VII has received a request for services to predict stack gas dispersion and land contact points in a hilly area where existing models may not be applicable. The specific request involves a lead smelter site in the Ozark Mountains in southeast Missouri, and the State agency wants to determine maximum fallout areas at ground levels for optimum location of air (SO_2) sampling stations. It is believed that remote determination of the principal ground impact area could be made using LIDAR plume tracing techniques. Development of a good plume tracing method would appear to have extensive application in control, as well as monitoring programs. If equipment is available for development and test application, we urge immediate action and offer cooperation in such a test.

A mutual interest to EPA and the Soil Conservation Service of USDA is the measurement of soil erosion (both water and windborne). Present monitoring of soil erosion and its effects is inadequate to evaluate the problems and to develop control programs. Aerial measurement would be preferable to ground level monitoring because of the great magnitude and extensiveness of this work.

Information for preparation of this report was provided by Mr. Dale B. Parke, Chief, Monitoring Branch, and Mr. Dewayne E. Durst, Chief, Program Support Branch (Air), Region VII.

REMARKS

By RUSSELL W. FITCH, E P A

LAS VEGAS SENSOR WORKSHOP
LAS VEGAS, NEVADA
October 10, 1973

Good afternoon. Thanks for inviting me to discuss our needs for improved sensor technology. This session has been extremely useful in helping me to understand the state-of-the-art and what we can expect in new sensors in the next few years.

Region VIII of Environmental Protection Agency includes the states of Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming. I will not discuss our needs related to your current sensor development programs in monitoring land use changes, oil spills, salinity in large lakes and estuaries, and algae levels. Obviously, all of these applications are of interest to our region, and we look forward to using them.

Instead, I will concentrate on describing three specific needs for remote monitoring which I feel should receive more attention: saline seeps, non-point pollution, and recycled water.

The Governor of Montana established an Emergency Committee to recommend a plan for stopping the increase of seeps which are destroying more land than coal strip mining. Water seeps through the ground to the surface and is recognizable by its characteristic white crusty appearance. These seeps tend to be circularly shaped and are about 1/2 acre. Plant growth in and around the seeps does occur, but it's usually different from the surrounding land. Sensors could possibly be used to locate the seeps, measure their size and rate of growth.

Non-point pollution problems are a major concern to EPA Region VIII. The area is heavily irrigated leading to salinity increases in nearby streams and ultimately the Colorado River. Agricultural chemicals are used widely. Remote sensing is needed to measure salinity and salinity increases. Possibly, insitu conductivity probes could be used to sense the salt and transmit this information to a satellite or airplane.

Other areas where remote monitoring could be used to support our non-point program are:

(1) Count the number of feedlots, cattle and land area

(2) Area of irrigated land

(3) Area and system configuration of irrigation canals and ditches

(4) Slope and soil composition of land carrying away pesticides and herbicides

Water is becoming more and more scarce in Colorado, Utah, and the other western states. Cities will increasingly consider reusing the effluent from their wastewater treatment facilities. This will create several problems. It will be necessary to measure the quantity and location of water since water rights are involved. It will be necessary to estimate spring run-off from melting snow since this will affect water supply. It will also be necessary to measure the amount of bacterological and virological contamination (this is probably impossible to do remotely).

It's interesting to postulate on how the regional offices of EPA will use remote sensing. I visualize two types of uses: continuous and special monitoring in case of an event. Regional offices should have one or two specialists trained in interpreting the continuously obtained data. This could be data on land use, saline seeps, oil spills, etc. Somehow they should have the ability to verify their observations either with additional sensing or expert analysis. This will be important in legal contests.

In the case of an oil spill or similar event, ground truth data will probably be necessary. People designing remote sensing systems should be sensitive to these additional needs. Possibly, the remote sensing system could handle the collection and transfer of ground truth data.

The ultimate judge in the effectiveness of remote sensing is the public. Can data obtained by remote sensing be used to improve their response to environmental hazards? How can weather information be integrated with remote sensing data? How will the data be released? Can the weather forecaster use the data to help convince people to stay our of their cars or away from downtown areas?

These questions, regarding how remote sensors can be used to increase human response to environmental hazards, should be investigated.

Remarks by

DR. DOUGLAS LONGWELL
EPA, Region IX

at the
Second Annual Conference on Remote Sensing

I am pleased to be here today representing EPA, Region IX at this Second Annual Conference on Remote Sensing. The Pacific Southwest Region includes the states of Arizona, California, Hawaii, Nevada; American Samoa, the territory of Guam and the Trust Territory of the Pacific Islands.

Region IX encompasses 10% of the nation's total land area, 18% of federally owned land, and 39% of Indian lands. The area is vast in scope, stretching over 6000 miles from the deserts of Nevada and the snow-peaked high Sierras to the lush tropical jungles of South Pacific atolls.

Eleven percent of the U.S. population resides in Region IX, where the rate of population growth is double the national average. Over half of its 23 million inhabitants are concentrated in two metropolitan areas - the San Francisco Bay Area and the Los Angeles San Diego Metropolitan Area.

Environmental problems besetting our Region are as complex and contrasting as is the topography of the land. Consider for a moment the social and environmental issues involved in the control of growth in Los Angeles versus the need to establish the mere rudiments of a sanitary system among the villages of the far-flung Caroline Islands.

It is for such geographic reasons as well as the vast differences in the needs of the states and territories that remote sensing techniques have such great application to environmental monitoring problems in Region IX.

Several major studies utilizing advanced remote sensing techniques have taken place within Region IX. Examples include an ongoing study of Lake Tahoe using remote sensing techniques to detect algal growth and sediment plumes in the Lake. This program is being conducted as a cooperative effort among the states of California and Nevada, NASA Ames Research, and EPA Region IX.

Another recent study, one conducted by the NEIC Denver, was an extensive aerial survey of the San Francisco Bay Area to identify outfalls by using photographic and thermal infrared imagery.

Thus far, we have centered our application of remote sensing techniques around specific situations related directly to enforcement activities. In two recent surveys, we have used aerial photography for this purpose.

From photograph 1a, one can see the newly installed ocean outfall at Moss Landing, California. Under normal conditions, no plumes should be visible from the outfall. However, in photograph 1b, a closer and oblique view, the appearance of a plume suddenly becomes much more apparent. In still a more detailed view, oblique view 1c, the existence of the plume is confirmed. The existence of these plumes, as documented by aerial photography, led scientists to investigate a nearby PG&E outfall. This investigation is currently ongoing and a second photo mission is now being planned to investigate both outfalls more closely. This time, during the flyover, ground truth will be used to more accurately reflect the conditions at the outfalls.

In another instance, aerial photographs were taken in the Los Angeles area to detect and document a sediment plume allegedly resulting from the operations of a nearby construction site. Photograph 2a gives an overview of the area, showing the two sources identified as outfalls. This is followed by photograph 2b, a closer oblique view of outfalls 1 and 2. Note the detail and appearance of the sediment plume. The next photographs 2c and 2d show a vertical view of outfalls 1 and 2, and then a vertical view of outfall 3.

Because of the success achieved in our initial attempts at remote sensing and monitoring, Region IX is now working on two other aerial photography missions. The first involves a photo survey of oil fields in the Bakersfield area, an established oil-producing area in south central California which still contains hundreds of producing wells. The purpose of the survey is to determine if open oil sumps and spills can be detected from the air using standard photo survey techniques in both a timely and economical manner. The Bakersfield area (and other oil-producing areas in California) contain hundreds of producing wells, many of which are located in remote areas. A traditional ground inspection would be both expensive and time-consuming.

The second mission involves a photo survey of the Las Vegas - Lake Mead area. The main purpose of this survey would be to establish a photo map to aid in the placement of sampling stations. Such a map should help measureably in the establishing of a water quality monitoring network.

At present, our specific regional needs reflect our commitment to enforcement activities.

In the near future, we would like to see more support given to NERC-Las Vegas in order to make aerial imagery, such as shown here today, more available to all EPA regions. This support could be direct fiscal support for aerial photography flights such as is now given to support the Oil and Hazardous Materials Spill and Spill Prevention programs. Another type of support could be development of active training programs to teach the methods and applicability of remote sensing at the regional level, with focus on regional programs. Such programs could establish a basic photo interpretative capability in each region and also serve to introduce more sophisticated methods as they become available.

NOTE: (Unfortunately, the photographs were not received prior to submission for publication.)

REGION X ENVIRONMENTAL MONITORING REQUIREMENTS AND APPLICATIONS

Ralph R. Bauer

Region X is fortunate to have generally clean air and an abundance of high quality water. With a few notable exceptions, abatement of point waste sources is proceeding well enough that we look to have our point source problems reasonably under control within the next five years. Point source control over liquid waste discharges is largely complete today in the Willamette River. The resulting water quality improvement is a celebrated success story.

That's the good news! Now for the bad news. Although water quality in the Willamette River is good, some water quality problems persist and may well worsen with time. Recent intensive mass balance-type surveys throughout the Region suggest strongly that point source control alone will not completely solve the water quality problems of many of our rivers. These surveys have confirmed the long held suspicion that non-point sources of pollution are a significant problem in Region X. Taking the Upper Snake River as an example, we can account for only about 32% of the phosphorous being carried in the river. This inability to reconcile point sources with the observed river burden is common and covers both conservative and non-conservative parameters. We have been forced to conclude that unless we can identify, quantify and control non-point pollution sources, our ultimate environmental objectives may never be fully realized.

Being intermittent and geographically wide spread, non-point sources of pollution are, by their nature, difficult to access. Region X has an area of responsibility covering 845,000 square miles and a tidal coastline stretching in excess of 38,000 square miles. Because of the size of our Region and the nature of our problems, surveillance needs cannot be satisfied through ground surveys alone. Resource requirements would be prohibitive. For example, the State of Alaska estimates that it would cost in excess of one billion dollars to conduct limnological surveys on all of their lakes which show signs of eutrophication. We have therefore looked upon the development of remote sensing with great interest.

Examples of Region X known or potential problems for which we see potential remote sensing support applications include:

1. Fugitive dust presumed to originate from agricultural activities and unpaved roads.

2. Urban runoff quality and quantity.

3. Stream sedimentation and temperature increases due to logging operations.
4. Particulates resulting from slash burning.
5. Leaching from solid waste dumps.
6. Irrigation return flows.
7. Animal feeding operations.
8. Abandoned mine drainage.
9. Eutrophication.
10. Oil spills.
11. Radioactivity accidental releases.

At the request of Region X, the National Field Investigation Center--Denver and NERC--Las Vegas have conducted aerial imagery missions to support the Region X NPDES permit program. Coincidentally, we are also evaluating the utility of this aerial imagery in our surveillance program. Applications have been limited to water problems and have included:

1. An inventory of animal feedlots in Idaho and Eastern Oregon.
   9x9 False Color IR
2. An outfall inventory in Puget Sound including an evaluation of dispersion patterns of large point sources, and a documentation of oil films on Puget Sound.
   Thermal IR
   9x9 False Color IR
   4.5x4.5 True Color
   Multiban
3. Algal productivity and sedimentation studies on Lake Coeur d'Alene and American Falls Reservoir. The Lake Coeur d'Alene study included ERTS Satellite imagery--in both cases chlorophyll a, transparency and algal growth potential tests were conducted for ground truth data.
   9x9 False Color IR
4. A non-point source inventory on the Willamette River.
   9x9 False Color IR

Requirements and Applications

The results of the aforementioned applications of remote sensing in Region X are not yet available. We anticipate that the results will be helpful but of somewhat limited value. In terms of data utility the biggest weakness we see with aerial imagery is the inability to determine quantitative chemical concentrations of toxicants and nutrients. Additional weaknesses are the inability to describe concentration with depth and the inability to penetrate cloud cover. To identify a problem qualitatively is, in our view, no longer sufficient. In an era where all our decisions must be evaluated in terms of the trade offs involved, quantitative data is required. We hope remote sensing can provide much of the required quantitative data..

Scope of Research Needs

Office of Enforcement and General Counsel
National Field Investigations Center, Denver
Arthur W. Dybdahl, Physicist, Remote Sensing Programs

The following represents a brief presentation of the requirements of the Office of Enforcement in the developemnt of technical and operational aspects of the Remote Sensing Programs.

1) Interdisciplinary coordination between physicists, biologists, geologist, microbiologist, organic chemists, inorganic chemists, mining specialists, etc. to better define the scope and depth of tasks related to the dilution of water/air pollutants in the environment. An example would be to have aquatic biologists help us with the definition of features/characteristics that would distinguish between various groups of and species of algae found in the aquatic environment.

2) Remote Sensing keys must be developed for each class of industrial and municipal facilities and discharges. Each key would consist of a complete catalogue of facility configurations, chemical/biological nature, color, physical characteristics of every discharge associated with a particular facility. The keys will be extensively used in the interpretation and analysis of remote sensing data.

3) 24-hour remote sensing capability is a must for the Enforcement Program. Research must be carried out for the definition and design of equipment and technical applications of active airborne detection systems. The research effort must be reduced to practice in a clear, concise manner in order to satisfy all legal requirements.

4) One manifestation of the Remote Sensing Program must fall in the area of the identification and quantification of all types of pollutants in the aquatic and atmospheric environments. This will involve a great deal of laboratory and field investigations to achieve the goal.

5) The nonlinear optical properties of waste water in search of viable pollutant fingerprints and dilution techniques mentioned in (4). An ERN has already been submitted to EPA, ORD requesting support in this area.

6) Oil detection is an important requirement. Oil slicks are quite easy to locate but, oil/grease emulsified in water is not. A detection medium for this later case must be developed. The mixture poses a greater threat to biota in the aquatic environment than does a slick.

7) Air quality airborne capability, in real time, that can readily be applied to enforcement is a firm requirement. This will involve a detailed investigation of sampling and detection techniques readily available and further defining future requirements.

8) From an interagency and intra-agency point of view all remote sensing techniques should be pooled together for the good of everyone. What are the various techniques? How good are they? How can each one be improved?

9) Lastly, ERTS data can be a real boon to EPA. There presently exists a major problem. We are unable to get the ERTS digital tapes and transparencies from NASA Goddard Space Center. EPA could be an effective prime user of this data if NASA would live up to its promises on data availability. A functional agreement must be negotiated between NASA and EPA to provide short time retrieval of the satellite data for our use. EPA, ORD is requested to take the initiative in order to effect such an agreement.

SESSION X

COMMENTS

CHAIRMAN

MR. JOHN D. KOUTSANDREAS

OFFICE OF MONITORING SYSTEMS, OR&D

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES

2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON REMOTE SENSING PROGRAMS
FOR EARTH RESOURCE SURVEYS

December 5, 1973

MEMORANDUM

TO: Dr. Willis Foster, Deputy Assistant Administrator for Monitoring
Environmental Protection Agency

FROM: Dr. Arthur G. Anderson, Chairman Arthur G. Anderson
Committee on Remote Sensing Programs for Earth Resource Surveys

SUBJECT: Review of the EPA's Remote Sensing Activity as presented at the
Second Conference on Environmental Quality Sensors
October 10-11, 1973, Las Vegas, Nevada

In response to your request the CORSPERS Panel on Environmental Measurements attended the Environmental Protection Agency's Second Conference on Environmental Quality Sensors at the National Environmental Research Center, Las Vegas, Nevada, on October 10-11, 1973, to review the Agency's remote sensing activities and perhaps make recommendations for future programs. While the panel's preliminary reaction was reported by Dr. Virginia Prentice, Chairman of the Panel, at the closing session of the conference, this memorandum constitutes CORSPERS' formal response to your Agency.

The Environmental Measurements Panel was impressed with the breadth and scope of environmental problems recognized by EPA as being amendable to possible solution by remote sensing techniques. EPA's active involvement with NASA and other federal agencies in the Earth Resource Survey Program is a sound investment in future capabilities. Because of the highly transient nature of many environmental quality parameters, a closer association with the NOAA remote sensing programs than was evident by the papers presented at the conference might be beneficial. As you know, the environmental information needs of both NOAA and EPA have significant common characteristics for near real time measurements, broad synoptic measurements and selected precise point measurements of the environment. The evolutionary thrust of the NOAA programs should lead to a data base of considerable significance to your agency.

It is recognized that the total span of an agency's interest and activity cannot be adequately described at a single two day conference. However, based on this limited exposure, the panel concluded that the research program could be strengthened in the following areas:

1. Several technologies are either not being used or used to their best advantage. For example:
    - a. Use of high resolution absorption spectroscopy to man and/or measure atmospheric constituents. Concentration of some typical pollutants can be determined with this technique to within a few parts per billion.
    - b. Use of the 3.7 to 4.0 micrometer band for water temperature measurements. Atmospheric and humidity corrections are negligible and the radiations are much more sensitive to temperature differences in this band as compared to the 8 to 14 micrometer band currently of interest in the Skylab sensors and in the ERTS thermal channel.
    - c. Manual or human interpretation techniques are generally inadequate to extract timely environmental quality data for both R & D and operational purposes. More emphasis should be placed on the development and use of advanced techniques, including automatic digital processing.
2. Current research work on automatic computer processing is principally based on the use of unique computer programs and large computers. A major emphasis in the development of software programs and the use of computers should be to provide programs more generally useful in the research and user community.
3. Strong emphasis should be placed on the development of reliable sensors that can make in situ measurements of critical environmental quality parameters via the DCS spacecraft system.
4. Strong emphasis should be placed on the development of techniques to calibrate remote sensors so that the data can be used as legal evidence in protection standards enforcement proceedings.

5. Finally, the Panel suggested that greater progress should be possibl towards meeting critical measurement requirements by first identifyi each pollutant measurement goal with its most appropriate measuremen technique, i.e., in situ monitoring, aircraft overflight measurement or broad synoptic coverage by space borne sensors, and then concentrate research and development effort on those sensor and technique combinations showing the greatest promise.

The Committee appreciates the opportunity offered to the Environmental Measurements Panel to attend and participate in the Conference at Las Vegas, Nevada. The Committee is looking forward with pleasure to continued participation with your agency in its efforts to protect our environment.

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